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**OPACITY AND MASS EMISSION RELATIONSHIP IN
FORGING AREAS OF LARGE CALIBER METAL PARTS FACILITIES**

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**US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
LARGE CALIBER
WEAPON SYSTEMS LABORATORY
DOVER, NEW JERSEY**

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19. KEY WORDS (Continue on reverse side if necessary and identify by block number)		
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A 21-month study was conducted to determine the relationship between opacity and mass emissions at the forging areas of large caliber metal parts facilities. Numerous particulate emission tests, concurrent with the operation of a transmissometer, were conducted at the uncontrolled exhausts of the Erie press line at Scranton Army Ammunition Plant (SAAP), Scranton, Pennsylvania, and the forging process at Flinchbaugh Products, Inc., Red Lion, Pennsylvania.		

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Tests results indicate that a strong correlation does exist between particle concentration and optical density at the 95% confidence level. Through a least-squares linear regression analysis of data points, the best-fit line for the total data base is defined. It is reasonable to predict particle concentration values from measured values of optical density (or opacity) by use of the preceding empirical relationship. Eighty-three percent of the variation-of-optical-density values can be attributed to variation in particle concentration. Variations in particle size distributions can account for a portion of the remaining 17%.

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INTRODUCTION

This report presents the results of a twenty-one-month study of the relationship between opacity and mass emissions at the forging areas of large caliber metal parts facilities. The major effort of the study was to perform a technical evaluation of the uncontrolled exhaust at the Erie press line at the Scranton Army Ammunition Plant (SAAP) operated by Chamberlain Manufacturing Corporation in Scranton, Pennsylvania. Technical evaluation consisted of performing numerous particulate emission tests, concurrent with the operation of a transmissometer, as well as analyzing process operating conditions. To evaluate emission and process characteristics at different forging facilities, two additional forge shops were visited. Particulate emission and opacity tests were performed at the forging facility of Flinchbaugh Products, Inc., in Red Lion, Pennsylvania, while process and opacity observations were recorded at the forge shop of Chamberlain Manufacturing Corp. in New Bedford, Massachusetts. These additional plant inspections provided a basis for evaluating emission characteristics between forge shops.

Since the emissions from the forging operations, which JACA observed, did not exhaust to particulate control devices before entering the atmosphere, it was not apparent that a correlation between opacity and particle concentration would exist. Several studies at industrial facilities such as power plants, cement kilns, and asphalt plants showed that a reliable correlation between opacity and particle concentration did exist [1,2,3]. However, these studies were conducted on controlled exhaust streams, following a control device. After the control device, the exhaust characteristics (especially particle size distribution) are likely to be much more uniform than an

uncontrolled exhaust stream. Varying exhaust characteristics were thought to be the limiting factors in this study. Indeed, because of the possibility of excessive variability of forge shop exhausts, the primary purpose of this study was to determine if an empirical relationship between opacity and particulate mass concentration could be established. The study was to describe this relationship for the purpose of estimating particulate mass emissions from opacity data recorded at similar forging operations.

BACKGROUND

A brief description of the forging process is warranted to obtain a basic understanding of the mechanism by which emissions are generated. Although there are similarities among the forging operations that JACA observed, there are also striking differences which affect the emission characteristics, and thus the reliability of the mass emission/opacity relationship. It is not the intention of this section of the report to evaluate process variations relative to observed emission characteristics, but rather to provide an overview of the forging process and insight to the limitations of the mass emission/opacity relationship.

The three forging operations that were observed manufacture large caliber shells for the United States Army. These shells may have diameters of 155 mm, 175 mm, or approximately 200 mm. The forging presses are characterized as closed die-type, where heated, pre-cut steel billets are formed to the desired shape through sequential mechanical operations.

The Erie press line at the SAAP is a three-step process consisting of preforming, piercing, and drawing operations. Preforming and piercing use a

punch and die arrangement to form a cavity in the hot steel billet (approximately 2,200° F) and to shape the steel according to the dimensions of the die. The solid punch is forced into the metal which is placed in a closed, cylindrical die cavity. This process produces a cavity in the steel billet by displacement without removal of the metal; in addition, the metal takes the form of the die cavity. Preforming and piercing are essentially the same type of operations except that the punches which are used for each are shaped differently. The preforming punch has a blunt end, while the piercing punch is elongated and comes more to a point. The drawing operation is the last phase of the shell forging process. In this operation, the partially formed shell is forced through a series of rings by the drawing punch. This procedure elongates or draws the shell as it passes through the rings.

The Erie press line at the SAAP is totally automated, in that the shells are automatically moved from one process phase to the next. In addition, lubricating oil is automatically applied to the punches and the die cavities. Only one person is required to operate the Erie press line.

In contrast to the Erie press line, the forging process at Flinchbaugh Products, Inc. requires 7 or 8 people to operate. The Flinchbaugh forging process also consists of three steps: descaling, preforming and extrusion, and drawing. However, the process is different than the Erie press at the SAAP, because the shell must be manually moved with manipulators from one process step to the next and lubricating oil is manually swabbed on the punch and die cavity. The manual nature of the Flinchbaugh shop limits production to approximately 60 shells per hour, while the SAAP Erie press line produces about 120 shells per hour. There are other differences between the Erie press line at the SAAP and the Flinchbaugh press line, but they will not be

discussed at this point.

Aerosols are generated during the forging process because of the lubricating oils which are used to prevent the hot metal from adhering to the punch and die cavity. The punch is coated with lubricating oil by simply dipping the punch in an oil reservoir (dip tank) or manually swabbing the punch with oil. The die cavity is lubricated by automatic injection of oil through the sides of the die cavity or by manual swabbing. The punch and die arrangement is lubricated prior to each billet entering the die cavity. When the lubricating oil in the die cavity and on the punch contacts the hot billet, a dense cloud of fumes results. This is often accompanied by intense flames at the die cavity and residual burning of oil on the punch. It is assumed that much of the oil vaporizes on contact, and subsequently condenses when drawn off by the exhaust fan. Since the lubricating oil contains substantial quantities of graphite (25 to 30% or more), the aerosol obviously contains graphite particles. In addition, it is likely that particles are formed through the thermal decomposition of the oil. Basically, the aerosol generated by the forging process may be characterized as a mixture, primarily solid particles dispersed with oil droplets.

An additional characteristic of the forging emissions is that they vary temporally, because of the cyclic nature of the process. Forging emissions are not continuous, but are rather erratic, increasing and decreasing in both intensity and duration throughout the forging cycle. The temporal fluctuation is short term (with peaks occurring every 45 to 90 seconds) and regular, as long as the presses are operating properly. Emission peaks occur at each process step when the punch and oil come in contact with the hot metal. The

emissions decrease and subside when an individual step is complete. Because there is more than one shell being processed at any one time, the resulting emissions are a mixture of particulates from the various forging steps. At each process step, the steel temperature and oil mixture may be different so that the resulting particulate emissions vary among steps and combine in the exhaust stack.

From this brief discussion, it is obvious that there are numerous parameters associated with the forging process which may affect the emissions at an individual forge shop and may cause emissions to differ between forge shops. These parameters include:

- Shell production rate
- Steel temperature
- Type of lubricating oil
- Quality of lubricating oil
- Quantity of oil used
- Method of oil application

While the process variations may affect emission characteristics, a detailed analysis of the relationship was not undertaken. Only shell production rates could be determined during the testing phase of this study. Information relative to oil quality and usage, and steel temperatures was neither available nor routinely recorded at the plants. For this reason, it was not possible to adequately evaluate process conditions relative to emission characteristics. The remainder of this report will present the results of JACA's testing program and will not discuss specifics of the forging process.

STUDY METHODOLOGY

The major emphasis of this study was to determine the relationship between opacity and particle mass concentration at the uncontrolled exhaust of the Erie press line at the forge shop of the SAAP. This was done through numerous field tests of both opacity and mass emissions. It was established early in the project that, of the six press lines at the SAAP, the Erie press line was most accessible and convenient for testing, and that it would be operating during JACA's testing program.

After the initial testing phase at the SAAP, it was decided that other forge shops should be visited to evaluate emission characteristics relative to those at the SAAP. Flinchbaugh Products, Inc. in Red Lion, Pennsylvania permitted JACA to perform particulate emission and opacity tests at their facility, because they were in need of the test information. JACA also inspected the forge shop of Chamberlain Manufacturing Corp. in New Bedford, Massachusetts, but no particulate emission tests were performed at this facility. The New Bedford forge shop will only be discussed in general terms, since no particulate emission tests were conducted.

Testing Procedures

A total of fifty-seven particle mass emission tests were conducted during the study period. For all but two of these particulate test runs, opacity data was recorded during the entire test period.

JACA's initial assessment of the exhaust of the Erie press line at the SAAP consisted of four EPA Method 5 test runs and two particle sizing tests

using a Brinks impactor. Opacities were recorded by a certified observer for all but two of the six test runs. Subsequent to the initial assessment, stack opacities were monitored with a single-pass transmissometer (Datatest Corp., Model 90A).

Forty-five particulate emission tests were conducted at the Erie press line of the SAAP, while twelve test runs were conducted at the Flinchbaugh forge shop. Various test methods were used during this study because data on both particle size distribution and total mass concentration were required. The original plan was to conduct all particulate tests in accordance with EPA Method 5 testing procedures and that the impinger catch would also be analyzed. However, after the initial tests at the SAAP it was decided that an in-stack filter assembly could be used and the tests could be conducted in accordance with EPA Method 17 procedures. It was thought that more test runs could be conducted without compromising the test results. JACA did perform two additional EPA Method 5 tests at the Flinchbaugh forge shop to determine the compliance status of the facility relative to the emission regulations of the Pennsylvania Department of Environmental Resources. The breakdown of the number of particulate tests conducted and the method and equipment used is as follows:

- SAAP Erie Press Line (Total of 45 Test Runs)
 - Four tests per EPA Method 5 procedures
 - Two particle sizing tests with a Brinks impactor
 - Nine particle sizing tests with a Gelman Sciences 7-stage cascade impactor (and preimpactor stage and back-up filter)
 - Thirty tests per EPA Method 17 procedures using a NAPP, Inc. in-stack filter assembly

- Flinchbaugh Products, Inc. Forge Shop (Total of 12 Test Runs)
 - Two tests per EPA Method 5 procedures
 - One particle sizing test with a Glean Sciences 7-stage cascade impactor (and preimpactor stage and back-up filter)
 - Nine tests per EPA Method 17 procedures using a NAPP, Inc. in-stack filter assembly.

Whenever possible, the "front half" particulate catch and the impinger catch were both analyzed. The impinger catch was analyzed by chloroform and ether extracts (condensibles) as well as by 0.2 μ m membrane filtration.

Testing Site

A primary concern in this opacity/mass emission study was to choose a sampling location where there was an adequate length of straight ductwork prior to the sampling ports. At both the Erie press line and the Flinchbaugh forge shop the choice of sampling locations was limited.

Figure 1 and Figure 2 illustrate the sampling locations at the Erie press line and the Flinchbaugh forge shop, respectively. For the Erie press line, the transmissometer was located downstream from the stack sampling ports. This was reversed for the Flinchbaugh forge shop. Both sampling locations are upstream of the exhaust fan. For all test runs (except the two Method 5 tests at Flinchbaugh) only one sampling port was used. The exhaust ducts were traversed parallel to the light beam of the transmissometer and twenty points were sampled for each test run. The sampling duration was 2, 3, or 4 minutes per test point, depending on the anticipated grain loading. Thus,

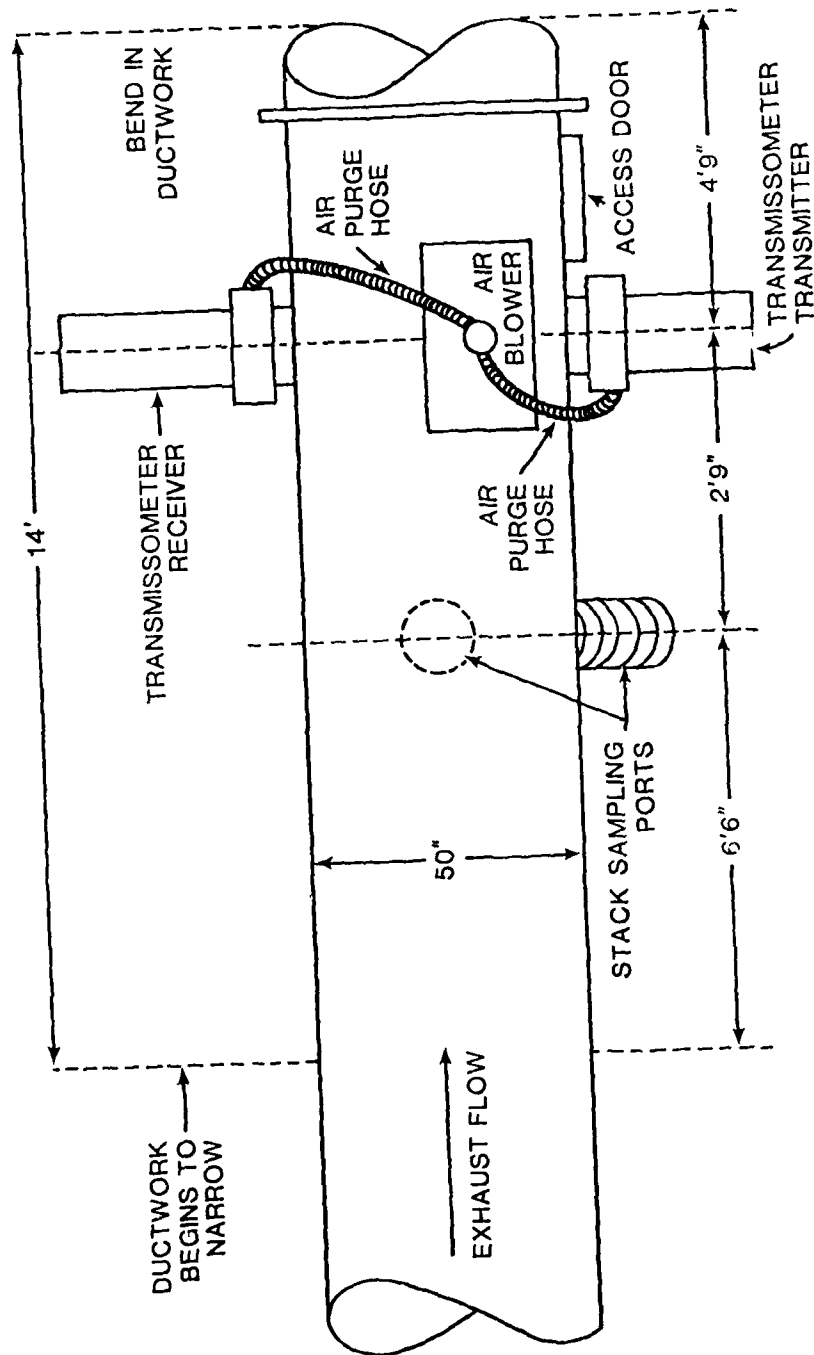


Figure 1. Sampling Location on the Horizontal Ductwork (View from Above) Coming from the Erie Press Line at the Scranton Army Ammunition Plant (SAAP), Scranton, PA.

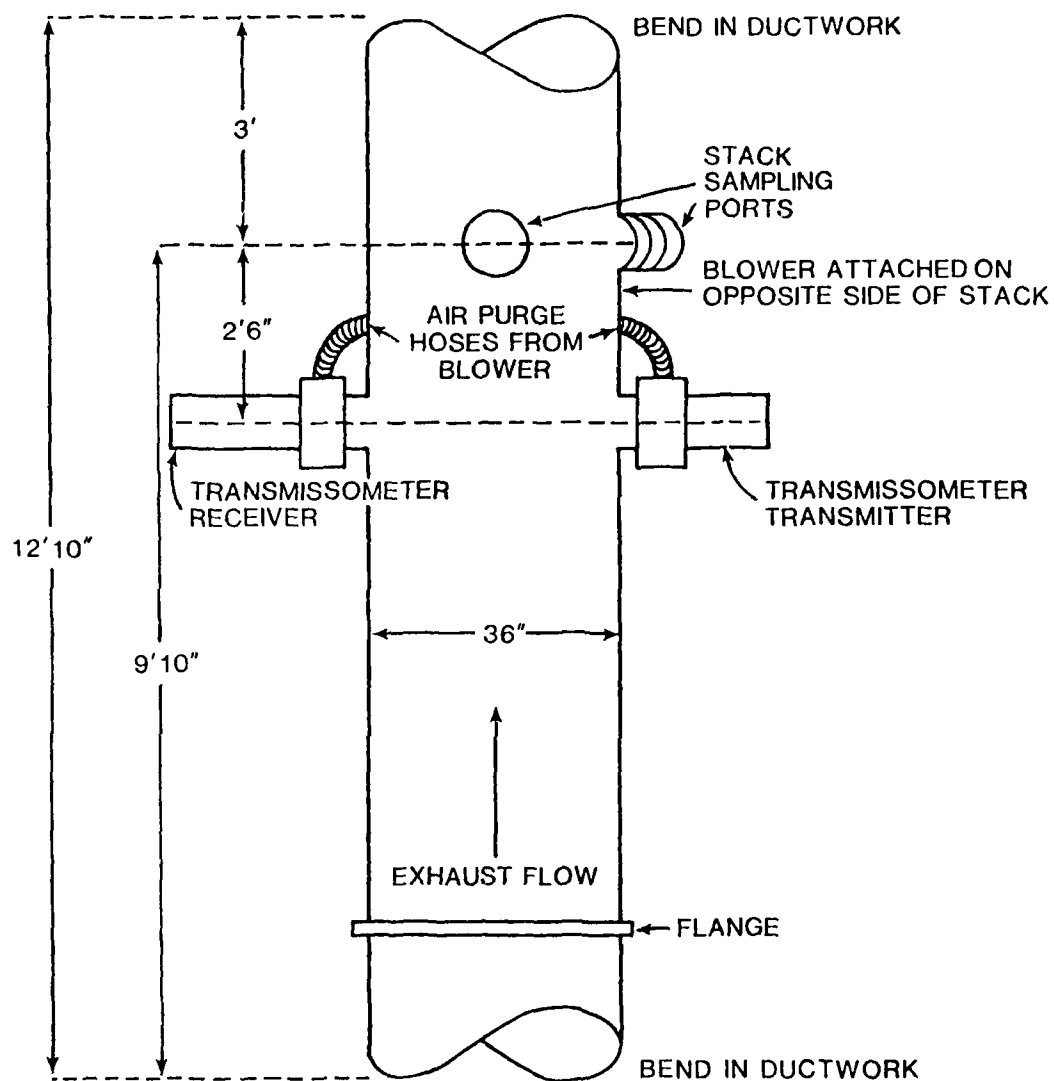


Figure 2. Sampling Location on the Vertical Ductwork Coming from the Forging Operation at Flinchbaugh Products, Inc., Red Lion, PA.

test runs were generally 40, 60, or 80 minutes long. However, the EPA Method 5 tests at Flinchbaugh were 120 minutes long, because two sampling ports were used. In all cases, the transmissometer was operated over the entire stack testing period.

PARTICULATE EMISSION TEST RESULTS

Table 1 and Table 2 present the results of the particulate emission tests at the Erie press line and the Flinchbaugh forge shop, respectively. These summary tables show consistency among the testing parameters at both press lines. The exhaust characteristics (such as flow rates, temperature, moisture, and gas analysis) are consistent and dependent on ambient conditions. The exhaust fan pulls large quantities of air through a hood which covers the entire forging process, so the exhaust is mostly ambient air.

For the purpose of this study, several of the test runs were invalidated because of sampling or analysis problems. Seven tests at the Erie press line were invalidated. Five test runs (SAAP Method 5 #1, Method 5 #4, IS #4, IS #7, and Impactor "G") were discounted because the isokinetic factor was outside of the acceptable range (90 to 110%). Test run SAAP IS #12 was invalid because the impingers broke and the impinger catch could not be analyzed. Test SAAP Impactor "F" was discounted for total particulate concentration analysis because the nozzle wash was spilled. Only one of the Flinchbaugh tests, Flinch. IS #5, was invalidated because the isokinetic factor was outside the acceptable range. These invalid test runs, as well as tests where no opacity data was available, were not considered in subsequent analysis of data.

The total particulate concentrations (gr/dscf) from both forging processes are quite low, considering the fact that the exhausts are uncontrolled. They range from 0.0094 gr/dscf to 0.0682 gr/dscf for the Erie press line, and from 0.0052 gr/dscf to 0.0089 gr/dscf for the Flinchbaugh forge shop. Generally speaking, the emissions from the Flinchbaugh forge shop are much lower than those of the Erie press line at the SAAP, undoubtedly because

Table 1

SUMMARY OF PARTICULATE TESTS AT THE ERIE PRESS LINE OF THE SCRANTON ARMY AMMUNITION PLANT

	SAAP Method 5 #1	SAAP Method 5 #2	SAAP Method 5 #3	SAAP P.S. (Brinks) #1	SAAP Method 5 #4	SAAP P.S. (Brinks) #2	SAAP IS #1	SAAP IS #2	SAAP IS #3	SAAP IS #4	SAAP IS #5	SAAP Imp. #8"
Test Date	11/14/79	11/14/79	11/14/79	11/15/79	11/15/79	11/15/79	9/2/80	9/2/80	9/3/80	9/3/80	9/4/80	9/4/80
Production Rate (shells/hr)	125.0	128.0	115.0	115.0	119.0	110.0	121.0	112.0	106.3	79.2	117.0	118.5
Barometric Pressure (in Hg)	29.626	29.567	29.610	29.744	29.630	29.538	29.290	29.090	29.520	29.520	29.530	29.530
Static Pressure (in Hg)	-0.272	-0.272	-0.287	-0.294	-0.309	-0.309	-0.125	-0.125	-0.125	-0.125	-0.125	-0.125
Absolute Stack Pressure (in Hg)	29.354	29.295	29.323	29.450	29.321	29.229	29.165	28.965	29.395	29.395	29.405	29.405
Stack Gas Velocity: FPS	79.43	79.29	81.40	--	80.07	--	83.69	87.65	81.61	87.55	81.59	82.21
FPM	4,765.6	4,757.1	4,865.2	--	4,804.1	--	5,021.2	5,223.3	4,893.7	5,252.8	4,895.2	4,962.7
Percent Moisture	0.49	0.58	0.37	--	0.43	--	1.68	2.54	1.40	1.90	2.85	0.83
Gas Flow Rate: ACFM	64,911	64,805	66,335	--	65,506	--	68,464.1	71,219.0	66,793.8	71,737.9	66,746.0	67,775.6
SCFM	62,054	62,060	63,643	--	62,400	--	64,494.3	61,774.7	64,122.0	67,272.9	62,400.9	62,502.8
DSCFM	61,750	61,700	63,403	--	62,132	--	63,410.7	63,155.3	63,271.3	60,014.4	60,595.1	62,281.5
Stack Temperature (" F)	84.5	82.4	81.4	78.9	85.9	87.2	100.5	102.0	100.0	93.1	95.0	100.0
Dry Gas Volume Sampled (dscf)	50.35	50.55	52.5	8.096	52.0	12.08	52.65	38.00	44.06	19.06	25.55	61.90
Sampling Duration (min.)	60	60	60	90	60	90	60.0	42.0	57	25	40	80
Std. Dry Gas Volume Sampled (dscf)	47.67	47.64	49.41	7.90	49.36	11.39	47.64	33.79	41.98	17.79	23.65	56.47
Isokinetic Factor	109	108	111	--	111	--	107	109	101	170	109	107
Gas Analysis: CO ₂	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.5
O ₂	20.3	20.4	20.4	20.3	20.3	20.3	20.47	20.47	20.47	20.47	20.67	20.07
H ₂	79.6	79.6	79.6	79.7	79.7	79.7	79.53	79.53	79.53	79.53	79.43	79.43
CO	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Molecular Weight of Stack Gas	28.75	28.75	28.78	--	28.77	--	28.64	28.45	28.47	28.61	28.55	28.74
Particulate Collected (Gms):												
Nozzle	0.0273	0.0287	0.0243	0.0029	0.0228	0.0033	0.0047	0.0042	0.0031	0.0087	0.0097	0.0321
Probe	0.0036	0.0006	0.0028	0.0039	0.0064	0.0092	--	--	--	--	--	--
Glassware (Before Filter)	0.0224	0.0120	0.0078	0.0034	0.0068	0.0051	--	--	--	--	--	--
Filter	0.0246	0.0345	0.0321	0.0069	0.0481	0.0049	0.0224	0.0130	0.0129	0.0058	0.0026	0.0283
Total Front Half	0.0749	0.0759	0.0671	0.0221	0.0841	0.0224	0.0271	0.0212	0.0360	0.0145	0.0183	0.067
Insoluble Impingers	--	--	--	--	--	--	0.0005	0.0007	0.0015	0.0005	0.0012	0.0012
Glassware (After Filter)	--	--	--	--	--	--	0.0007	0	0.0017	0.0007	0	0.0068
Total (Including Insolubles)	--	--	--	--	--	--	0.0284	0.0219	0.0392	0.0158	0.0195	0.0687
Condensibles	0.0093	0.0021	0.0009	--	0.0049	--	0.0005	0.0046	0.0009	0.0032	0.0032	0.0056
Total (Including Condens.)	0.0817	0.0779	0.0680	--	0.0890	--	0.0289	0.0265	0.0461	0.0190	0.0227	0.0743
Particle Concentrations (gr/dscf):												
Front Half	0.0242	0.0246	0.0207	0.0431	0.0263	0.0305	0.0087	0.0097	0.0132	0.0126	0.0118	0.0166
Front Half + Insolubles	--	--	--	--	--	--	0.0092	0.0100	0.0144	0.0137	0.0126	0.0183
Total (Including Condens.)	0.0270	0.0252	0.0210	--	0.0278	--	0.0094	0.0121	0.0169	0.0165	0.0147	0.0203
Emission Rate (lb/hr):												
Front Half	12.81	13.01	11.25	--	14.01	--	4.73	5.25	7.15	7.13	6.13	8.80
Front Half + Insolubles	--	--	--	--	--	--	5.00	5.41	7.80	7.75	6.54	10.02
Total (Including Condens.)	14.21	13.33	11.41	--	14.80	--	5.11	6.55	9.16	9.38	7.63	10.84

(Continued)

Table 1

(Continued)

	SAAP 15 #7	SAAP 15 #8	SAAP 15 #9	SAAP 15 #10	SAAP 15 #11	SAAP 15 #12	SAAP 15 #13	SAAP 15 #14	SAAP 15 #15	SAAP 15 #16	SAAP 15 #17	SAAP 15 #18	SAAP 15 #19	SAAP 15 #20
Test Date	9/5/80	9/5/80	9/5/80	9/5/80	10/14/80	10/14/80	10/14/80	10/15/80	10/15/80	10/15/80	10/15/80	10/16/80	10/16/80	10/16/80
Production Rate (shells/hr)	121.5	112.5	129.0	105.5	94.5	121.5	115.5	100.5	112.5	91.5	110.9	121.5	121.5	121.5
Barometric Pressure (in Hg)	29.530	29.540	29.460	29.450	29.523	29.449	29.469	29.606	29.528	29.597	29.571	29.570	29.570	29.570
Static Pressure (in Hg)	-0.125	-0.163	-0.170	-0.130	-0.235	-0.154	-0.191	-0.175	-0.147	-0.147	-0.147	-0.147	-0.147	-0.147
Absolute Stack Pressure (in Hg)	29.405	29.377	29.300	29.320	29.288	29.295	29.278	29.431	29.381	29.450	29.423	29.423	29.423	29.423
Stack Gas Velocity - FPS	80.37	87.46	82.03	79.97	86.25	84.38	84.36	83.16	84.01	84.77	84.52	87.14	87.14	87.14
FPM	4,819.5	4,937.4	4,925.1	4,793.3	5,174.2	5,053.0	5,061.9	4,937.3	5,100.6	5,076.0	5,071.2	5,272.4	5,272.4	5,272.4
Percent Moisture	3.17	1.06	2.5	2.12	0.67	1.70	0.487	0.68	0.636	0.60	0.63	0.72	0.72	0.72
Gas Flow Rates - ACFM	65,713.9	67,473.5	67,153.7	65,424.7	70,633.8	69,145.9	69,130.4	68,137.9	69,658.9	69,459.5	69,257.4	71,731.4	71,731.4	71,731.4
SCFM	61,804.4	63,120.2	62,471.7	60,645.1	67,395.0	65,171.2	67,647.1	65,015.0	65,596.8	65,446.2	66,562.7	68,751.5	68,751.5	68,751.5
DSCFM	59,892.4	62,444.8	60,861.1	58,371.6	65,951.1	64,395.7	67,372.3	64,572.4	65,145.6	64,105.0	66,147.3	68,521.5	68,521.5	68,521.5
Stack Temperature (°F)	91.7	93.9	95.0	95.0	87.0	89.5	90.0	85.3	91.1	90.5	80.3	85.6	85.6	85.6
Dry Gas Volume Sampled (dscf)	26.40	61.77	25.84	25.19	26.43	27.04	64.59	25.6	62.7	26.66	26.55	27.25	27.25	27.25
Sampler Duration (min.)	40	80	40	40	40	40	80	40	80	40	40	40	40	40
Std. Dry Gas Volume Sampled (dscf)	24.87	57.30	23.95	23.35	24.17	25.53	60.32	24.77	59.35	25.11	25.49	25.67	25.67	25.67
Isokinetic Factor	115	108	109	109	105	110	110	106	106	107	108	104	104	104
Gas Analysis - CO ₂	0.25	0.25	0.25	0.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
O ₂	20.27	20.27	20.27	20.27	20.1	20.1	20.1	20.1	20.1	20.1	20.0	20.0	20.0	20.0
H ₂	79.48	79.49	79.48	79.48	79.9	79.9	79.9	79.9	79.9	79.9	80.0	80.0	80.0	80.0
CO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Molecular Weight of Stack Gas	28.52	28.73	28.53	28.63	28.73	28.69	28.80	28.74	28.74	28.74	28.73	28.75	28.75	28.75
Particulate Collected (Gss):														
Nozzle	0.0195	0.0303 ^c	0.0116	0.0165	0.0157	0.0266	0.0733 ^c	0.0177	0.0351 ^c	0.0199	0.0173	0.0121	0.0121	0.0121
Probe	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Glassware (Before Filter)	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Filter	0.0104	0.0223 ^d	0.0110	0.0187	0.0096	0.0099	0.0135 ^d	0.0073	0.0145 ^d	0.0107	0.0137	0.0329	0.0329	0.0329
Total Front Half	0.0300	0.0526	0.0226	0.0352	0.0253	0.0365	0.0868	0.0250	0.0496	0.0306	0.0310	0.0450	0.0450	0.0450
Insoluble Impingers	0.0005	0.0010	0.0011	0.0006	0.0004	0.0011	0.0005	--	0.0001	0.0031	0.0007	0.0001	0.0001	0.0001
Glassware (After Filter)	0.0024	0.0037	0.0024	0.0023	0.0005	0.0005	0.0011	0.0007	0.0017	0.0007	0	0	0	0
Total (Including Insolubles)	0.0329	0.0558	0.0261	0.0381	0.0262	0.0381	0.0884	0.0257	0.0514	0.0314	0.0317	0.0451	0.0451	0.0451
Condensibles	0.0019	0.0093	0.0076	0.0060	0.0026	0	0	--	0	0	0	0	0	0
Total (Including Condens.)	0.0348	0.0656	0.0337	0.0441	0.0288	0.0381	0.0884	--	0.0514	0.0314	0.0317	0.0451	0.0451	0.0451
Particle Concentrations (gr/dscf):														
Front Half	0.0166	0.0142	0.0146	0.0232	0.0155	0.0221	0.0222	0.0146	0.0131	0.0188	0.0175	0.0271	0.0271	0.0271
Front Half + Insolubles	0.0204	0.0153	0.0169	0.0252	0.0161	0.0230	0.0276	0.0160	0.0136	0.0211	0.0192	0.0277	0.0277	0.0277
Total (Including Condens.)	0.0216	0.0179	0.0217	0.0291	0.0177	0.0239	0.0276	--	0.0136	0.0211	0.0192	0.0277	0.0277	0.0277
Emission Rate (lb/hr):														
Front Half	9.56	7.56	7.60	11.83	8.90	12.18	12.81	8.64	7.32	10.50	10.52	15.93	15.93	15.93
Front Half + Insolubles	10.48	8.14	8.77	12.81	9.22	12.71	13.05	8.88	7.59	11.60	10.78	15.97	15.97	15.97
Total (Including Condens.)	11.04	9.60	11.43	14.62	10.13	12.71	13.05	--	7.59	11.80	10.75	15.97	15.97	15.97

(Continued)

Table 1

(Continued)

	SAAP 15 #16	SAAP 15 #17	SAAP 15 #18	SAAP 15 #19	SAAP 15 #20	SAAP 15 #21	SAAP 15 #22	SAAP 15 #23	SAAP 15 #24	SAAP 15 #25
Test Date	10/16/80	10/16/80	10/17/80	10/17/80	10/17/80	10/21/80	10/21/80	10/21/80	10/22/80	10/22/80
Production Rate (shells/hr)	123.75	127.5	125.0	133.5	115.5	129.0	132.0	117.0	129.0	118.5
Barometric Pressure (in Hg)	29.530	29.450	29.540	29.530	29.530	29.210	29.210	29.210	29.530	29.530
Static Pressure (in Hg)	-0.147	-0.117	-0.260	-0.230	-0.150	-0.118	-0.118	-0.118	-0.260	-0.118
Absolute Static Pressure (in Hg)	29.383	29.333	29.280	29.300	29.380	29.092	29.092	29.092	29.270	29.412
Stack Gas Velocity: FPS	86.47	85.56	86.36	85.60	85.95	86.71	87.65	87.53	87.67	87.11
FPM	5,180.2	5,133.6	5,181.7	5,196.1	5,156.9	5,202.8	5,259.0	5,251.9	5,260.2	5,266.6
Percent Moisture	0.937	1.03	1.23	2.12	1.05	0.90	0.99	1.19	0.872	0.13
Gas Flow Rate: ACFM	70,856.3	70,125.0	70,762.0	70,970.7	70,427.3	71,054.6	71,837.9	71,698.4	71,854.3	69,627.4
SCFM	67,259.8	64,833.4	67,459.0	65,324.3	65,411.1	67,596.8	66,903.8	64,289.6	67,531.6	65,556.4
DSCFM	65,195.9	64,231.5	66,582.0	64,918.2	65,219.0	66,928.4	66,248.2	65,500.7	65,942.7	65,499.7
Stack Temperature (°F)	86.2	93.8	81.6	92.4	94.0	79.6	91.2	95.2	96.2	90.0
Dry Gas Volume Sampled (dscf)	62.06	26.69	47.61	26.96	26.97	26.93	27.45	27.62	49.21	26.31
Sampling Duration (min.)	60	40	60	40	40	40	40	40	60	40
Std. Dry Gas Volume Sampled (dscf)	57.60	24.51	45.01	24.96	25.05	25.33	25.37	25.28	44.95	24.58
Isokinetic Factor	102	165	88	107	107	105	107	107	105	105
Gas Analysis: CO ₂	0.0	0.0	0.07	0.07	0.07	0.0	0.0	0.0	0.0	0.0
O ₂	20.0	20.0	19.9	19.9	0.0	20.2	20.2	20.2	20.2	20.1
H ₂	80.0	80.0	80.03	80.03	19.9	79.8	79.8	79.8	79.8	79.9
CO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Molecular Weight of Stack Gas	28.64	28.63	28.66	28.57	28.69	28.71	28.70	28.69	28.72	28.73
Particulate Collected (Gms):										
Nozzle	0.0161	0.0126	0.0327	0.0154	0.0115	0.0178	0.0374	0.0395	0.0570	0.0118
Probe	--	--	--	--	--	--	--	--	--	--
Glassware (Before Filter)	--	--	--	--	--	--	--	--	--	--
Filter	0.0234	0.0290	0.0081	0.0243	0.0229	0.0324	0.0227	0.0447	0.0163	0.0115
Total Front Half	0.0395	0.0416	0.0408	0.0397	0.0344	0.0502	0.0601	0.0847	0.0733	0.0233
Insoluble Impingers	0.0006	0.0012	0.0040	0.0010	0.0039	0.0006	0.0028	0.0008	0.0017	0.0031
Glassware (After Filter)	0	0	0	0	0	0.0025	0.0025	0.0045	0.0019	0.0020
Total (Including Insolubles)	0.0401	0.0428	0.0448	0.0407	0.0383	0.0527	0.0629	0.0892	0.0750	0.0264
Condensibles	0.0233	0.0034	0	0	0	0.0014	0.0008	0.0035	0.0059	0.0045
Total (Including Condens.)	0.0634	0.0462	0.0448	0.0407	0.0383	0.0541	0.0637	0.0927	0.0809	0.0309
Particle Concentrations (gr/dscf):										
Front Half	0.0496	0.0260	0.0151	0.0245	0.0212	0.0277	0.0195	0.0239	0.0252	0.0146
Front Half + Insolubles	0.0493	0.0268	0.0165	0.0252	0.0214	0.0295	0.0278	0.0272	0.0273	0.0159
Total (Including Condens.)	0.0560	0.0289	0.0165	0.0252	0.0214	0.0305	0.0237	0.0293	0.0322	0.0214
Emission Rate (lb/hr):										
Front Half	28.31	14.31	8.62	13.66	11.85	15.92	11.07	13.42	16.46	8.12
Front Half + Insolubles	28.40	14.75	9.41	14.00	11.95	17.09	12.95	16.27	16.68	8.64
Total (Including Condens.)	31.95	15.92	9.41	14.00	11.95	17.49	13.17	16.45	17.02	13.02

(Continued)

Table 1

(Continued)

	SAAP 10/22/80	SAAP 10/23/80	SAAP 10/23/80	SAAP 10/23/80	SAAP 10/23/80	SAAP 10/23/80	SAAP 10/23/80	SAAP 10/23/80	SAAP 10/23/80
Test Date	10/22/80	10/23/80	10/23/80	10/23/80	10/23/80	10/23/80	10/23/80	10/23/80	10/23/80
Production Rate (wells/hr)	121.0	115.5	81.0	102.0	101.5	141.5	115.5	124.5	117.0
Barometric Pressure (in Hg)	29.530	29.494	29.450	29.430	29.462	29.482	29.451	29.430	29.490
Static Pressure (in Hg)	-0.118	-0.150	-0.150	-0.150	-0.151	-0.152	-0.150	-0.150	-0.150
Absolute Stack Pressure (in Hg)	29.412	29.340	29.300	29.280	29.310	29.330	29.301	29.280	29.340
Stack Gas Velocity (ft/s)	86.07	83.91	85.47	84.81	87.63	86.23	87.39	86.37	87.72
Percent Moisture	5.1614	5.1316	5.1362	5.0767	5.2519	5.2738	5.2116	5.1234	5.2632
Gas Flow Rate (A/FM)	70,499.2	72,484.6	70,136.4	63,137.8	71,102.1	72,056.6	71,583.5	66,599.2	71,879.5
Gas Flow Rate (S/FM)	67,941.3	72,551.1	67,575.6	64,816.3	68,510.6	67,453.3	67,016.5	67,730.0	63,403.4
Gas Flow Rate (D/FM)	67,236.2	61,500.1	65,475.1	63,466.2	65,292.7	67,151.8	67,114.6	67,401.9	68,110.1
Stack Temperature (°F)	78.4	81.7	83.8	73.8	84.7	91.5	93.7	87.0	91.3
Dry Gas Volume Sampled (scf)	47.03	20.19	20.46	41.3	27.65	27.65	27.12	21.95	26.71
Sampling Duration (min)	60	40	40	6	40	40	40	40	40
Std. Dry Gas Volume Sampled (scf)	11.77	26.14	26.44	4.13	26.14	26.11	26.09	26.66	24.93
Isokinetic Factor	106	107	106	59	106	101	107	107	102
Gas Analysis (vol %)									
O ₂	20.1	20.1	20.1	20.1	20.1	20.1	20.1	20.1	20.1
N ₂	79.9	79.9	79.9	79.9	79.9	79.9	79.9	79.9	79.9
CO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Molecular Weight of Stack Gas	28.96	28.71	28.73	28.74	28.77	28.74	28.77	28.75	28.76
Particulate Collection (wt %)									
Nozzle	0.0042	0.0118	0.0147	0.1756	0.0112	0.0171	0.0110	0.0220	0.0931
Probe	--	--	--	--	--	--	--	--	--
Glassware (before Filter)	--	--	--	--	--	--	--	--	--
Filter	0.0129 ^a	0.0126	0.0125	0.0160	0.0123	0.0141	0.0143	0.0105	0.0137
Total Front Half	0.0074	0.0244	0.0272	0.1916	0.0235	0.0312	0.0253	0.0325	0.1068
Insoluble Impurities	0.0008	0.0020	0.0006	0.0005	0.0004	0.0005	0.0004	0.0011	0.0001
Glassware (After Filter)	0.0034	0.0002	0.0002	0.0001	0.0002	0.0002	0.0002	0.0002	0.0002
Total (Including Insolubles)	0.0516	0.0265	0.0320	0.1527	0.0341	0.0409	0.0357	0.0338	0.1071
Condensibles	0.0014	0.0022	0.0007	0	0.0001	0.0006	0.0005	0.0002	0.0033
Total (Including Condens.)	0.0530	0.0288	0.0327	0.1527	0.0342	0.0415	0.0362	0.0340	0.1104
Particle Concentrations (gr/dscf)									
Front Half	0.0162	0.0140	0.0165	0.0507	0.0139	0.0187	0.0151	0.0194	0.0660
Front Half + Insolubles	0.0175	0.0153	0.0190	0.0510	0.0142	0.0246	0.0157	0.0201	0.0662
Total (Including Condens.)	0.0181	0.0165	0.0194	0.0510	0.0143	0.0249	0.0158	0.0202	0.0682
Emission Rate (lb/hr)									
Front Half	9.31	8.40	10.64	29.73	8.10	10.50	8.78	11.23	38.52
Front Half + Insolubles	10.13	9.15	11.91	29.80	8.34	14.15	8.90	11.61	38.63
Total (Including Condens.)	10.41	9.91	11.15	29.90	8.39	14.36	9.03	11.69	39.82

^aImpinger damaged - could not analyze back half of sampling train.^bSpilled nozzle with test invalidated.^cThis weight (for use in tests) is the combined weight of the nozzle and precipitator washes.^dThis weight (for use in tests) is the combined weight of the traps for soot and backup filter.

Table 2

SUMMARY OF PARTICULATE TESTS AT FLEET-BOROUGH PRODUCTS, INT'L. RED LION, PA. Fertilizer Shop

	Period 1 5/19/77				Period 2 5/20/77				Period 3 5/21/77				Total
	IS #1	IS #1	IS #2	IS #3	IS #4	IS #5	IS #6	IS #7	IS #8	IS #9	IS #10	IS #11	IS #12
Test Date	5/19/77	5/19/77	5/20/77	5/20/77	5/20/77	5/20/77	5/20/77	5/20/77	5/21/77	5/21/77	5/21/77	5/21/77	5/21/77
Production Rate (shells/hr)	70.1	61.0	62.0	60.0	62.0	65.0	65.0	63.2	60.0	61.0	61.0	52.5	52.5
Oil Usage (gal/hr)	3.69	3.65	3.68	3.65	3.68	3.65	3.65	4.52	4.52	4.52	4.52	4.52	1.25
Oil Usage (gal/shell)	0.052	0.055	0.054	0.057	0.059	0.057	0.057	0.072	0.075	0.075	0.075	0.075	0.075
Barometric Pressure (in Hg)	29.19	29.133	29.210	29.210	29.240	29.24	29.24	29.24	29.24	29.24	29.24	29.24	29.24
Static Pressure (in Hg)	-0.272	-0.265	-0.265	-0.265	-0.235	-0.271	-0.265	-0.272	-0.267	-0.267	-0.267	-0.267	-0.267
Absolute Stack Pressure (in Hg)	29.925	28.868	28.955	29.955	29.065	29.015	29.015	29.015	29.023	29.014	29.014	29.014	29.014
Stack Gas Velocity: FPS	70.55	70.14	70.14	69.57	66.65	65.17	64.95	69.73	69.69	67.94	67.94	67.94	67.94
FPM	4,235.6	4,202.9	4,202.6	4,114.3	3,993.2	3,940.5	3,942.4	4,180.7	4,140.0	4,079.4	4,079.4	4,079.4	4,079.4
Percent Moisture	2.02	1.63	1.62	1.63	1.62	1.64	1.36	1.29	0.60	0.60	0.60	0.60	0.4
Gas Flow Rate: ACFM	29,933.7	29,740.7	29,733.3	29,079.6	28,265.4	28,083.3	27,559.3	29,570.4	29,291.5	28,633.7	28,425.6	28,045.9	28,045.9
SCFM	27,454.9	27,254.3	27,877.6	27,048.3	26,271.9	26,120.5	25,501.9	27,676.5	27,356.2	26,792.1	26,583.4	26,171.7	26,171.7
DSCFM	26,903.3	26,790.9	27,431.6	26,615.5	25,846.3	25,711.4	25,155.1	27,308.6	27,031.6	26,631.3	26,425.5	26,011.1	26,011.1
Stack Temperature (°F)	50.6	95.95	85	83.25	90.75	90.0	92.5	87.44	87.25	91.0	91.25	91.25	91.25
Dry Gas Volume Sampled (dscf)	87.64	45.13	44.28	43.52	42.13	55.34	53.64	87.65	43.65	43.62	42.94	79.56	79.56
Sampling Duration (min.)	120	60	60	60	60	60	120	60	60	60	60	120	120
Std. Dry Gas Volume Sampled (dscf)	10.14	40.91	41.52	40.53	33.38	51.68	49.43	81.70	40.43	39.99	39.33	72.77	72.77
Isokinetic Factor	10.4	110%	110%	110%	110%	111%	108%	108%	107%	108%	108%	108%	108%
Gas Analysis: CO ₂	0.05	0.05	0.05	0.05	0.05	0.05	0.05	-0-	-0-	-0-	-0-	-0-	-0-
O ₂	20.35	20.35	20.35	20.35	20.35	20.35	20.35	20.35	20.35	20.35	20.35	20.35	20.35
N ₂	79.50	79.50	79.50	79.50	79.50	79.50	79.50	79.50	79.50	79.50	79.50	79.50	79.50
CO	0.10	0.10	0.10	0.10	0.10	0.10	0.10	-0-	-0-	-0-	-0-	-0-	-0-
Molecular Weight of Stack Gas	28.60	28.64	28.64	28.61	28.64	28.65	28.67	28.67	28.74	28.74	28.74	28.74	28.74
Particulate Collected (Gns):													
Nozzle	0.0053	0.0058	0.0035	0.0052	0.0055	0.0059	0.0071	0.0073	0.0052	0.0025	0.0021	0.0021	0.0021
Probe	0.0037	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Glassware (Before Filter)	0.0036	-	0.0001	0.0001	0.0001	0.0001	-0-	0.0001	-0-	-0-	-0-	-0-	0.0001
Filter	0.0167	0.076	0.0034	0.0092	0.0030	0.0145	0.0170	0.0193	0.0159	0.0123	0.0122	0.0122	0.0122
Total Front Half	0.0313	0.0145	0.0174	0.0149	0.0171	0.0240	0.0244	0.0321	0.0215	0.0145	0.0143	0.0143	0.0143
Insoluble Impurities	0.0018	--	--	--	--	--	--	0.002	--	--	--	--	-0-
Glassware (After Filter)	0.0001	--	--	--	--	--	--	-0-	--	--	--	--	0.0001
Total (Including Insolubles)	0.0332	--	--	--	--	--	--	0.0343	--	--	--	--	0.0143
Condensibles	0.0127	0.0014	0.0014	0.0014	0.0014	0.0014	0.0036	0.0078	0.0016	0.0016	0.0016	0.0016	0.0016
Total (Including Condens.)	0.0459	0.0159	0.0188	0.0163	0.0185	0.0254	0.0180	0.0449	0.0231	0.0161	0.0159	0.0159	0.0159
Particle Concentrations (gr/dscf):													
Front Half	0.0060	0.0055	0.0064	0.0067	0.0067	0.0072	0.0045	0.0061	0.0072	0.0059	0.0059	0.0059	0.0059
Front Half + Insolubles	0.0064	--	--	--	--	--	--	0.0068	--	--	--	--	0.0068
Total (Including Condens.)	0.0098	0.0061	0.0059	0.0067	0.0072	0.0076	0.0056	0.0093	0.0069	0.0056	0.0056	0.0056	0.0056
Emission Rate (lb/hr):													
Front Half	1.39	1.26	1.50	1.30	1.48	1.59	0.97	1.41	1.63	1.35	1.87	1.19	1.19
Front Half + Insolubles	1.48	--	--	--	--	--	--	1.59	--	--	--	--	1.77
Total (Including Condens.)	2.03	1.40	1.62	1.41	1.60	1.69	1.21	1.92	1.74	1.51	2.00	1.21	1.21

of the differences in the processes, i.e., production rate, type of lube oil, lube oil usage, etc.

For the most part, the condensible particulates constitute a small percentage of the total particle concentration. The condensibles average approximately 7.3 percent (range 0 to 50.6%) of the total particulate weight for the Erie press exhaust and 11.2 percent (range 1.6 to 27.7%) for the Flinchbaugh exhaust. On several occasions, the weight percent of condensibles exceeded 20 percent (as high as 50.6%), but there was no obvious reason for these anomalies.

Three of the tests at the Erie press line resulted in an unusually large quantity of particulates captured in the nozzle of the sampling train (SAAP Imp. "F", SAAP Imp. "J", and SAAP IS #33). Test SAAP Imp. "F" was invalidated because of an obvious analysis error; the nozzle wash was spilled. However, it is not obvious why the other two test runs had nozzle washes which were more than four times greater in weight than the nozzle washes of similar test runs. It is possible that the large quantity of material in the nozzle is due to human error, such as hitting the probe against the stack wall. However, it is also possible that the large quantity of material in the nozzle is the result of random fluctuations of the emissions generated by the forging operation. It was assumed that there was not a problem with the sampling or analysis procedures, and that the unusually large weight of particulates in the nozzle was the result of process variations. Because of the weight of particulate in the nozzle, tests SAAP Imp. "J" and SAAP IS #33 yielded particle concentrations which were two to three times greater than the other tests.

Table 3 compares JACA's emission test results at the Erie press line and the Flinchbaugh forge shop with the test results from other forging operations. The table also contains basic operating parameters for the different forging facilities. For the purpose of comparison, JACA's average emission concentrations were separated according to the testing procedures used to determine the concentrations.

As seen from Table 3, JACA's test results from the Erie press line compare favorably with the test results from other press lines at the SAAP (Verson, John Deere, and Bliss #1 press lines). Average emission concentrations at the Erie press line are on the order of 0.0233 gr/dscf to 0.0368 gr/dscf, while particle concentrations from the Verson, John Deere, and Bliss #1 press lines are 0.0318 gr/dscf, 0.0298 gr/dscf and 0.0206 gr/dscf, respectively. At the SAAP, each press line uses the same type of lubricating oils (Quenchtex 500 and Texaforge 7571). According to SAAP personnel, the two lubricating oils are mixed in the dip tanks and the Texaforge 7571 lubricating compound (referred to as "hot punch") is applied to the die cavity. Both lubricating compounds are oil based, and the Texaforge 7571 contains a graphite additive (approximately 25%). The average production rates (shells per hour) of the four presses at the SAAP are also comparable (105 to 127 shells per hour), but the Verson press has a greater material throughput (pounds per hour) because it manufactures larger shells.

The particulate test results from the Flinchbaugh forge shop show average concentrations of 0.0052 gr/dscf to 0.0086 gr/dscf, which are one-third to one-fourth the concentrations from any of the forges at the SAAP. However, the Flinchbaugh test results are similar to the test results from the Chamberlain Manufacturing forge shop in New Bedford, Massachusetts. The

Table 3
PROCESS PARAMETERS AND EMISSION TEST RESULTS FROM VARIOUS SHELL FORGING OPERATIONS

Plant Location	Test Dates	Press Identification	Number of Process Stacks	Type of Shell (Approximate Weight)	Approximate Billet Temperature (°F) ^a	Type of Lubricating Oil(s) ^b	Average Production Rate (Shells/hr)	Number of Tests	Average Emission Concentration (gr/dt) ^c	Average Emission Rate (lb/hr)	Testing Organization	Test Method
SAAP (Chamberlain), Scranton, PA	3/4-26/73	Version 1	3	175 mm (115 lb)	2350 to Unknown	Quenchitec 500 Texaforge 7571	127	8	0.0015 ^d	6.01	U. S. Army	PMMA Method
SAAP (Chamberlain), Scranton, PA	3/4-26/73	John Deere ^e	3	155 mm (75 lb)	Unknown	Quenchitec 500 Texaforge 7571	105	2	0.0021 ^d	6.02	U. S. Army	PMMA Method
Chamberlain Mfg. Corp., New Bedford, Mass.	4/10/74 to 5/1/74	Version #3	3	Unknown (16 lb)	2200 to 1610	Marfuge 558 Marfuge 451	132	3	0.0009 ^d	2.91	19th	EPA Method 5
SAAP (Chamberlain), Scranton, PA	4/12/76	Press #1	2	155 mm (75 lb)	2000 to 1700	Quenchitec 500 Texaforge 7571	120	3	0.0015 ^d	0.03 ^f	Passnagel & Assoc.	EPA Method 5
SAAP (Chamberlain), Scranton, PA	11/14-15/79	Free	3	155 mm (75 lb)	2200 to 1700	Quenchitec 500 Texaforge 7571	128	23	0.0061 ^d	13.61	JACA Corp.	EPA Method 5
SAAP (Chamberlain), Scranton, PA	11/14-15/79	Free	3	155 mm (75 lb)	2200 to 1700	Quenchitec 500 Texaforge 7571	113	2	0.014 ^d	---	JACA Corp.	Gravimetric
Flintknapp Products Inc., Red Lion, PA	5/19 & 21/79	Baldwin (Modified)	3	155 mm M249 (48.5 lb)	2300 to 1850	Houghton "Hot Forging Agent 201"	67	2	0.005 ^d	1.93	JACA Corp.	EPA Method 5
Flintknapp Products Inc., Red Lion, PA	5/19/79	Baldwin (Modified)	3	155 mm M249 (48.5 lb)	2300 to 1850	Houghton "Hot Forging Agent 201"	63	8 ^g	0.005 ^d	1.52	JACA Corp.	EPA Method 17
Flintknapp Products Inc., Red Lion, PA	5/27/80	Baldwin (Modified)	3	155 mm M249 (48.5 lb)	2300 to 1850	Houghton "Hot Forging Agent 201"	52	1	0.0052 ^d	1.21	JACA Corp.	Gravimetric
SAAP (Chamberlain), Scranton, PA	9/27/80 to 10/23/80	Free	3	155 mm (75 lb)	2200 to 1700	Quenchitec 500 Texaforge 7571	115	27 ^h	0.0033 (+0.07) ^d	13.11 (+6.25)	JACA Corp.	EPA Method 17
SAAP (Chamberlain), Scranton, PA	9/27/80 to 10/23/80	Free	3	155 mm (75 lb)	2200 to 1700	Quenchitec 500 Texaforge 7571	116	29 ^h	0.0047 (+0.076) ^d	14.06 (+7.60)	JACA Corp.	Gravimetric

^aThis temperature range represents the temperature when the billet leaves the furnace and decreases until the last step is completed.

^bAll of these lubricants are oil based, except one, and contain 25 to 30% graphite. Marfuge 558 contains only 12% oil. When two oils are listed, they are both used in the process. They are mixed in certain proportions.

^cAverage emission concentration is the total concentration of front half plus condensibles.

^dAt the time of these tests, the lubricant was applied manually. Automatic systems have since been installed. See "Air Pollution Abatement Study for Hot Forging Operations" by Anderson-Nichols and Co., Inc., for Chamberlain Manufacturing Corp., Scranton, PA, January 1975.

^eThis concentration is the average of eight one-hour tests at three stacks. Concentrations were weighted by the individual stack flow rates and are weighted averages.

^fTwo of the four stacks were tested from this press line. Average concentration was weighted by the individual stack flow rates.

^gTwo stacks, North and South, were sampled simultaneously. Average concentration is weighted by the stack flow rates.

^hAnderson, Gordon L., and P. W. Kalika, "Report to Chamberlain Manufacturing Corporation, New Bedford, Massachusetts, on the Measurement of Particulate Matter Emissions from the No. 3 Forge Press System", The Research Corporation of New England, May 1974, revised August 1974.

ⁱOnly a portion of the exhaust was tested in the control system study. Passnagel and Associates, "Report of Evaluation Air Pollution Tests Conducted on the Two Charged (Vaport Scrubber Located at the Scranton Army Ammunition Plant, Scranton, PA, for Picatinny Arsenal on April 12, 1978." April 20, 1978.

^jTwo of JACA's tests were discounted because the isokinetic rate was greater than 110%.

^kOne of JACA's tests was discounted because the isokinetic rate was greater than 110%.

^lThree of JACA's tests were discounted, two because the isokinetic rate was greater than 110%, and one because no condensible analysis could be done.

^mOne of JACA's tests were discounted, one because the isokinetic rate was less than 95%, and one because the nozzle wash was stalled.

average emission concentration at the New Bedford forge shop was tested to be 0.0058 gr/dscf. The lubricating oil used at Flinchbaugh is designated as Hot Forging Agent 201 (HF 201), manufactured by E. F. Houghton and Co. This lubricating compound is oil based (approximately 50 to 65% oil) and contains 20 to 30 percent graphite. The lubricating compounds used at the New Bedford forge shop are designated as MacForge 599 and MacForge 958. MacForge 958 is water based, containing 12 percent oil and 24 percent graphite. MacForge 599 is oil based, with 48 percent oil and 30 percent graphite. A mixture of MacForge 599 and 958 is used in the dip tanks, while only MacForge 599 is used for swabbing the die cavity. The production rates are dissimilar for the Flinchbaugh and New Bedford forge shops.

No conclusions can be drawn about which process parameters are most important relative to the exhaust emission characteristics. It appears that the production rate and the quantity and type of lube oil used have a significant effect. Most probably a combination of process factors (including production rate, oil usage, method of oil application, etc.) account for the observed emission characteristics. This indicates that the particulate emission characteristics may vary from one press line to another, and thus any relationship between mass emissions and opacity is likely to be site-specific. As will be discussed in Section 5.1 of this report, there does appear to be a difference between the mass emission/opacity relationship which is statistically significant for the exhausts from the Erie press line at the SAAP and the Flinchbaugh forging operation.

OPACITY OBSERVATIONS

As previously discussed, each of the particulate mass emission tests was accompanied by opacity data which was recorded over the entire test period. For the most part, opacities were monitored with a Datatest, Model 90A, transmissometer. Figure 1 and Figure 2 show the positions of the transmissometer as installed on the exhaust ducts of the Erie press line at the SAAP and the Flinchbaugh forge shop, respectively. To provide a hard copy of opacity values, an Esterline Angus (minigraph) strip chart recorder was used. The recorder was operated concurrent with the mass emission tests.

Analysis of opacity data was straightforward; opacity values were obtained from the recorder charts and averaged over the sampling period for each test run. The Flinchbaugh opacity data exhibited a regular pattern of maximum and minimum opacities and a continuous curve. In this case the average opacity was determined by measuring the area under the curve with a planimeter and dividing by the total area for the entire test period. The opacity data from the Erie press line exhibited an erratic pattern and did not show a continuous curve. Since the chart recorder used pressure sensitive paper, the Erie press data exhibited a series of distinct dots (approximately 60 per minute) which varied considerably. The opacity data from the Erie press was analyzed by counting and recording the magnitude of the individual dots. The average opacity during a test period was simply the sum of the magnitudes of the opacity values divided by the total number of points which were counted.

Since the transmissometer was zeroed and the span was checked frequently, it was observed that for some tests the lenses were accumulating a thin layer of dust despite the fact that the air purge system was operated at all times. The zero and span were checked at the beginning and end of each day, and any other time that the process was not operating and the stack was clear. The lenses were also cleaned at the beginning of each day. Each time the zero and span were checked, the opacity increase was noted. According to the manufacturer, a one percent increase in opacity over a 24-hour period can be explained by the zero drift of the instrument. However, JACA was observing, at times, a 4 to 8 percent opacity increase, which can only be explained by dusting of the lenses. For this reason, some of the average opacity values were adjusted to account for the observed opacity increases when the stack was clear. Most of the opacity data from the Flinchbaugh forge shop and three test runs from the Erie press line were corrected to account for lens dusting. To make this correction, it was assumed that the opacity increases proceeded in a linear fashion, from the time the instrument was zeroed and calibrated at the beginning of each day until the zero position was again checked. The opacity increase was then subtracted from the recorded opacity data.

Table 4 is a summary of the mass emission and opacity data which was used in the final analysis phase of this study. Columns 6 and 7 of Table 4 illustrate the range of opacity values which were recorded. It should be noted in column 7 that the Flinchbaugh opacity data was also adjusted to account for the difference in emission characteristics and stack diameter between the Flinchbaugh forge shop and the Erie press line exhausts. This will be discussed in more detail in the next section of the report.

Table 4
SUMMARY: MASS EMISSION VERSUS CAPACITY DATA

Test Identification	Test Date	Sample Volume at Stack Conditions (ACF)	Total Weight (grams) ^a	Total Concentration (gr/ACF) ^b	Average Opacity (%) ^c	Average Opacity Corrected (%) ^d	Optical Density (Corrected) ^e	Comments
SAAP Method 5 #1	11/14/79	50.38	0.0830	0.0254	21.09 ^f	21.00	0.1023	
SAAP Method 5 #2	11/14/79	50.28	0.0779	0.0243	13.20 ^f	13.20	0.0615	
SAAP Method 5 #3	11/14/79	52.42	0.0680	0.0260	---	---	---	Isokinetic Factor = 111%, invalid
SAAP P.S. #1 (Brinks)	11/15/79	8.10	0.0221 ^f	0.0193 ^f	---	---	---	No capacity data, invalid
SAAP Method 5 #4	11/15/79	52.24	0.0890	0.0263	18.09 ^f	18.00	0.0862	Isokinetic Factor = 111%, invalid
SAAP P.S. #2 (Brinks)	11/15/79	12.10	0.0225 ^f	0.0237 ^f	16.90 ^f	16.90	0.0774	
Flinch Method 5 #1	5/19/80	89.19	0.0359	0.0079	13.64	9.67 ^h	0.0442	
Flinch IS #1	5/19/80	45.41	0.0159	0.0054	11.07	6.77 ^h	0.0176	
Flinch IS #2	5/20/80	45.35	0.0188	0.0054	9.20	6.97 ^h	0.0114	
Flinch IS #3	5/20/80	44.30	0.0163	0.0057	8.74	5.96 ^h	0.0068	
Flinch IS #4	5/20/80	41.07	0.0185	0.0056	9.22	5.60 ^h	0.0054	
Flinch IS #5	5/20/80	56.43	0.0254	0.0059	10.11	5.82 ^h	0.0061	Isokinetic Factor = 211%, invalid
Flinch IS #6	5/20/80	54.14	0.0180	0.0051	10.39	5.47 ^h	0.0044	
Flinch Method 5 #2	5/21/80	88.40	0.0449	0.0077	8.81	6.10 ^h	0.0273	
Flinch IS #2	5/21/80	43.44	0.0204	0.0072	11.48	7.65 ^h	0.0115	
Flinch IS #3	5/21/80	43.24	0.0170	0.0061	13.65	7.55 ^h	0.0143	
Flinch IS #9	5/21/80	42.27	0.0225	0.0072	12.63	6.62 ^h	0.0093	
Flinch Imp. "A"	5/28/80	27.79	0.0257	0.0059	7.12	4.65	0.0008	
SAAP IS #1	9/2/80	52.76	0.0280	0.0034	16.07	16.07	0.0061	
SAAP IS #2	9/2/80	39.12	0.0265	0.0107	15.29	15.29	0.0021	
SAAP IS #3	9/3/80	45.15	0.0341	0.0158	13.25	13.25	0.0017	
SAAP IS #4	9/3/80	19.33	0.0190	0.0152	13.40	13.40	0.0025	Isokinetic Factor = 120%, invalid
SAAP IS #5			Impingers connected incorrectly -- test stopped.					
SAAP IS #6	9/4/80	21.26	0.0277	0.0133	14.15	14.15	0.0053	
SAAP Imp. "B"	9/4/80	61.46	0.0743	0.0142	22.51	20.51 ^h	0.0092	
SAAP IS #7	9/5/80	21.21	0.0345	0.0197	21.05	21.05	0.1026	Isokinetic Factor = 115%, invalid
SAAP Imp. "C"	9/5/80	61.57	0.0556	0.0157	20.49	20.49	0.0195	
SAAP IS #8	9/5/80	26.42	0.0137	0.0153	23.15	23.15	0.1144	
SAAP IS #9	9/5/80	25.60	0.0141	0.0256	15.17	15.17	0.0714	
SAAP IS #10	10/14/80	26.57	0.0289	0.0157	17.30	17.30	0.0525	
SAAP IS #11	10/14/80	27.42	0.0301	0.0214	19.21	19.21	0.0426	
SAAP Imp. "D"	10/14/80	64.52	0.0381	0.0111	19.87	19.87	0.0627	
SAAP IS #12	10/15/80	26.09	0.0257 ^f	0.0157 ^f	15.12	15.12	0.0712	Front half only, invalid
SAAP Imp. "E"	10/15/80	62.45	0.0514	0.0127	18.24	18.24	0.0525	
SAAP IS #13	10/15/80	27.74	0.0344	0.0143	15.49	15.49	0.0711	
SAAP IS #14	10/16/80	26.92	0.0314	0.0130	19.31	19.31	0.0432	
SAAP IS #15	10/16/80	27.09	0.0351	0.0123	21.15	21.15	0.1017	
SAAP Imp. "F"	10/16/80	61.28	0.2190	0.0526	25.65	25.65	0.1207	Unusually high nozzle wash spilled nozzle wash, invalid
SAAP IS #16	10/16/80	26.76	0.0362	0.0265	27.63	27.63	0.1493	
SAAP Imp. "G"	10/17/80	47.82	0.0481	0.0155	20.39	20.39	0.0400	Isokinetic Factor = 88%, invalid
SAAP IS #17	10/17/80	26.80	0.0407	0.0234	22.35	22.35	0.1099	
SAAP IS #18	10/17/80	27.10	0.0447	0.0193	22.66	22.66	0.1116	
SAAP IS #19			Filter damaged -- this test not run.					
SAAP IS #20	10/21/80	31.83	0.0501	0.0241	29.35	27.35 ^h	0.1453	
SAAP IS #21	10/21/80	27.51	0.0397	0.0214	25.97	18.97 ^h	0.0914	
SAAP IS #22	10/21/80	27.40	0.0480	0.0270	22.42	22.42	0.1102	
SAAP Imp. "H"	10/21/80	49.14	0.0554	0.0171	26.05	26.05	0.1311	
SAAP IS #23	10/22/80	25.64	0.0512	0.0393	19.83	19.83	0.0906	Unusually high condensibles
SAAP IS #24	10/22/80	27.07	0.0381	0.0218	18.85	18.85	0.0907	
SAAP IS #25	10/22/80	27.79	0.0439	0.0227	20.17	20.17	0.0978	
SAAP Imp. "I"	10/22/80	48.05	0.0530	0.0170	18.20	18.20	0.0477	
SAAP IS #26	10/23/80	24.47	0.0238	0.0155	17.61	17.61	0.0451	
SAAP IS #27	10/23/80	27.46	0.0327	0.0184	15.90	15.90	0.0752	
SAAP Imp. "J"	10/23/80	41.61	0.1422	0.0503	15.04	15.04	0.0708	Unusually high nozzle and pre-impactor wash
SAAP IS #28			Filter damaged -- this test not run.					
SAAP IS #29	10/23/80	27.50	0.0242	0.0136	18.01	18.01	0.0962	
SAAP IS #30	10/23/80	27.01	0.0415	0.0137	19.67	19.67	0.0951	
SAAP IS #31	10/23/80	27.57	0.0463	0.0147	19.25	19.25	0.0926	
SAAP IS #32	10/23/80	26.95	0.0340	0.0195	18.17	18.17	0.0471	
SAAP IS #33	10/23/80	26.35	0.1130	0.0655	19.42	19.42	0.0330	Unusually high nozzle wash

^a The total weight of particulate collected in the front half of the train, plus filterable and condensible portion of the impactor catch (except where otherwise noted).

^b The total concentration is derived from the particle weight in the front half of the train, plus the filterable and condensible portion of the impactor catch (except where otherwise noted).

^c This average opacity is the raw opacity data obtained from the chart recorder.

^d This average opacity corrected is the raw opacity data corrected for various loss dusting as noted; all of the Flinch through data was also reduced to an equivalent opacity relative to the stack dusting and emission characteristics at the time peak time in operation.

^e Optical density was calculated from the corrected average opacity according to the relationship: Optical Density = $2.3 \log (1 - \text{Opacity})$.

^f Total weight and concentration do not include condensibles.

^g Opacity was determined by a certified observer.

^h Opacity corrected for loss dusting.

Table 4 illustrates the difference in opacity between the two forging operations. The exhaust of the Flinchbaugh forge shop exhibited average opacities (corrected) in the range of 4.68 percent to 9.67 percent, while the Erie press line exhaust showed opacities in the range of 13.20 percent to 27.63 percent. Obviously, the opacity values at the Erie press line are consistently higher than those at the Flinchbaugh forge shop. The particle concentration values follow this same general pattern. The following section will discuss the relationship between the corresponding particle concentration and opacity values listed in Table 4.

OPACITY/MASS EMISSION RELATIONSHIP

Opacity may be defined as a physical property of a medium representing the degree to which visible light is attenuated as the light traverses the medium. Opacity is expressed as:

$$\begin{aligned}\text{Opacity (\%)} &= (1 - T)100 \\ &= (1 - I/I_0)100\end{aligned}\tag{1}$$

where T = the transmittance of light

I_0 = the intensity of light incident on a medium

I = the intensity of light leaving a medium

It is obvious from the previous equation that opacity and transmittance are very simply related. Transmittance is measured by transmissometers by determining the intensity of incident light (I_0) and that leaving a medium (I). These two values are then used to calculate opacity.

The theoretical relationship between opacity and particle concentration may be defined by a simplified expression of the Beer-Lambert Law:

$$I = I_0 e^{-\alpha CL}\tag{2}$$

where C = particle concentration in terms of mass per unit volume

α = an extinction coefficient which is a function of particle size distribution, composition, and other particle characteristics

L = optical path length

I, I_0 = intensity of light leaving and incident on a medium

By combining equations 1 and 2, an alternate expression for opacity (as a decimal value) is as follows:

$$\text{Opacity} = 1 - e^{-\alpha CL} \quad (3)$$

One would expect from the preceding equation that the mass concentration of particulates in a gas stream could be predicted if all other quantities are known or measured. This is essentially what is done in theoretical and field (or actual) calculations. It should be realized that equation 3 is a simplified expression relating opacity and particle concentrations. There are several simplifying assumptions that are necessary to arrive at this relationship. For a more detailed account of this relationship, the reader is referred to the publications of Pilat and Ensor [4,5].

To discuss the relationship between mass concentration and opacity, it is convenient to introduce an additional quantity, optical density, which is frequently used in representing transmissometer data. Optical density (D) is defined as the logarithm to the base 10 of one over transmittance (T):

$$D = \log 1/T = - \log T \quad (4)$$

where D is expressed as a fraction which ranges from zero to one.

Since opacity is defined as $1 - T$, the relationship with optical density is expressed by:

$$D = - \log (1 - \text{opacity}) \quad (5)$$

By combining equations 3 and 5, an alternate expression for optical density is as follows:

$$D = - \log (e^{-\alpha CL}) \quad (6)$$

or

$$D = 0.434 \alpha CL \quad (7)$$

Equation 7 predicts that there is a linear relationship between optical density and particulate concentration. Manufacturers of transmissometers, such as Dynatron, Inc. [6], claim that this correlation can be established empirically through stack testing. At a given industrial location the diameter of the stack and thus the optical path length, L, would be known and a constant. Thus the expression relating optical density and mass concentration may be written as:

$$D = mC \quad (8)$$

where m is a proportionality constant and represents the slope of a straight line relating D with C.

In order to establish this empirical relationship at a given location it is necessary to determine numerous data points by stack sampling using an approved sampling train and method, and simultaneously monitor optical density with a transmissometer. Though one data point could be used to establish this relationship, the confidence in the relationship would be quite limited. To establish a degree of confidence in this optical density/mass emission relationship it is desirable to obtain a large number of data points over a range of emission concentrations and process conditions. With these data it is then possible to perform a linear regression analysis to generate the regression line and the confidence limits. The transmissometer data is time

averaged over the period of a stack test to determine a mean optical density value which is related to the measured mass concentration value. The mass concentration value is also a composite of sampling for a specified time interval at specified locations across the stack cross-section. The first assumption that is made then is that the average optical density and mass concentration over the sampling period (typically 1 to 2 hours for a stack test), adequately represents the stack conditions during that period. This is essentially what was done in this study.

This type of correlation appears straightforward. The correlation of optical density to mass emissions is valid as long as the particle size distribution, optical path length, and other particle properties (e.g., shape, composition) do not change significantly. These conditions are more likely to be fulfilled for sources with high efficiency control device, and where the emissions are generated by a continuous process rather than a cyclic or batch type process. High efficiency control equipment tend to narrow the particle size distribution by removing the larger particles. A continuous process indicates that the methods and conditions of particle generation are likely to be fairly constant, thus resulting in a more consistent particle distribution, shape, and composition. The validity of an optical density/mass emission correlation at a single plant is dependent on the variability of particulate properties and the process variations. To extrapolate the data generated at one plant to determine mass emissions from optical density at another plant, the particulate characteristics and the process must be very similar to the plant from which the correlation was derived. Between-plant as well as within-plant variations in the process and particle characteristics must be a matter of concern. The correlation can be developed

without knowing information on the particle size distribution but the size distribution and other scattering properties of the particles should remain constant for high correlation to be obtained.

Study Results: Optical Density vs. Mass Emissions

Table 4 summarizes the data which JACA used in this analysis of optical density versus mass emissions. Before discussing the study results it is necessary to explain some of the parameters contained in Table 4.

The main emphasis of this study was to relate optical density with particle mass concentrations as described by equation 8. JACA chose to represent the mass emissions in terms of grains per actual cubic feet of exhaust gas (gr/acf), instead of on a dry standard basis. The reduction of the particulate data to a dry standard basis artificially alters the concentration values, due to differences in stack moisture, temperature, and pressure. For example, two stacks may exhibit identical particle concentrations when expressed as gr/acf. However, if one stack has a moisture content of 10 percent by volume and the second has a moisture content of 5 percent by volume, the first stack will exhibit a higher mass concentration than the second, if the moisture alone is removed from the calculation. The mean spectral response of the transmissometer is in the range of 500 to 600 nm. There are water and carbon dioxide absorption bands in the near infrared region of the light spectrum (i.e., ~1,000 to 2,500 nm). Large opacity measurement errors could result for stack gases with high humidity due to the light absorption band of water. However, measurement errors due to the presence of water and carbon dioxide do not present a problem in this study, because these compounds are almost negligible in the exhausts we examined.

To compare the average opacity or optical density values obtained at the Flinchbaugh forge shop to those from the Erie press line at the SAAP, the opacity values for Flinchbaugh were corrected or reduced to an equivalent basis. This takes into account the differences between the stack diameters and the particle characteristics at the two forge shops. Corrections were performed in accordance with the following equation:

$$O_e = 1 - (1 - O_F)^{\frac{L_S \alpha_S}{L_F \alpha_F}} \quad (9)$$

where O_e = equivalent average opacity recorded at Flinchbaugh relative to that at the SAAP

O_F = average opacity at Flinchbaugh

L_S = 50 inches, stack diameter at the SAAP

L_F = 36 inches, stack diameter at Flinchbaugh

α_S = 0.0925, an extinction coefficient calculated from the opacity and mass emission data at the SAAP

α_F = 0.1641, an extinction coefficient calculated from the opacity and mass emission data at Flinchbaugh

While the corrected or equivalent opacity values for Flinchbaugh were used in the analysis of the total data base, the uncorrected opacity values were used when only the Flinchbaugh data was analyzed. This will be explained in the following paragraphs. The uncorrected opacity values for Flinchbaugh are not listed in Table 4.

The relationship between optical density and total mass concentration was established through computer analysis. Data was analyzed by the use of the Statistical Analysis System's General Linear Models Procedure, which is a

least squares linear regression model. Basically, this analysis scheme generated the "best fit" line passing through 0, for the data sets and tested the significance of the relationship between the optical density and mass concentration values.

To evaluate the differences between the Flinchbaugh and the Erie press line data and to determine if the test methods may have an affect on the study results, the total data base contained in Table 4, as well as subsets of the total data base, were analyzed. Eight different scenarios were considered in the analysis scheme. This included an analysis of:

1. All data collected during the study at both the Erie press line and the Flinchbaugh forge shop. Note that 9 test runs were invalidated as previously discussed. This data set consists of 48 paired points, sets of optical density and mass concentration values.
2. All data at both forge shops where the mass concentration was determined by the in-stack filter test method (all IS data). This data set consists of 35 paired points.
3. Data collected at the Erie press line, regardless of test method (all Erie data). This data set consists of 37 paired points.
4. Data collected at the Erie press line where the mass concentration was determined by the in-stack filter test method (IS data at Erie). This data set consists of 27 paired points.
5. Data collected at the Flinchbaugh forge shop, regardless of test method and before the opacity data was corrected or reduced to the equivalent basis (all uncorrected data at Flinchbaugh). This data set consists of 11 paired points.

6. Data collected at the Flinchbaugh forge shop, regardless of test method and after the opacity data was corrected (all corrected Flinchbaugh data). This data set consists of 11 paired points.
7. Data collected at the Flinchbaugh forge shop, where the mass concentration was determined by the in-stack filter test method and before the opacity data was corrected (original IS data at Flinchbaugh). This data set consists of 8 paired data points.
8. Data collected at the Flinchbaugh forge shop, where the mass concentration was determined by the in-stack filter test method and after the opacity data was corrected (corrected IS data at Flinchbaugh). This data consists of 8 paired data points.

The results of the computer analysis of the eight data sets listed above are summarized in Figures 3 through 18. For each of the eight data sets, two graphs were generated. These two graphs, for each data set, are plotted on a single page for ease of comparison. The top graph (Figures 3, 5, 7, 9, 11, 13, 15, and 17) on each page represents a scatter plot of the particle concentration and optical density values contained in the data set. The bottom graph (Figures 4, 6, 8, 10, 12, 14, 16, and 18) on each page represents the best fit of data in the graph at the top of the page by a least squares linear regression analysis. This linear model essentially predicts optical density values from particle concentration values so that the best line is constructed, relating the two variables. For these analyses, the best fit line was forced to go through the origin, since it is obvious that optical density would be zero if there were no particles in the stack at the time of measurement.

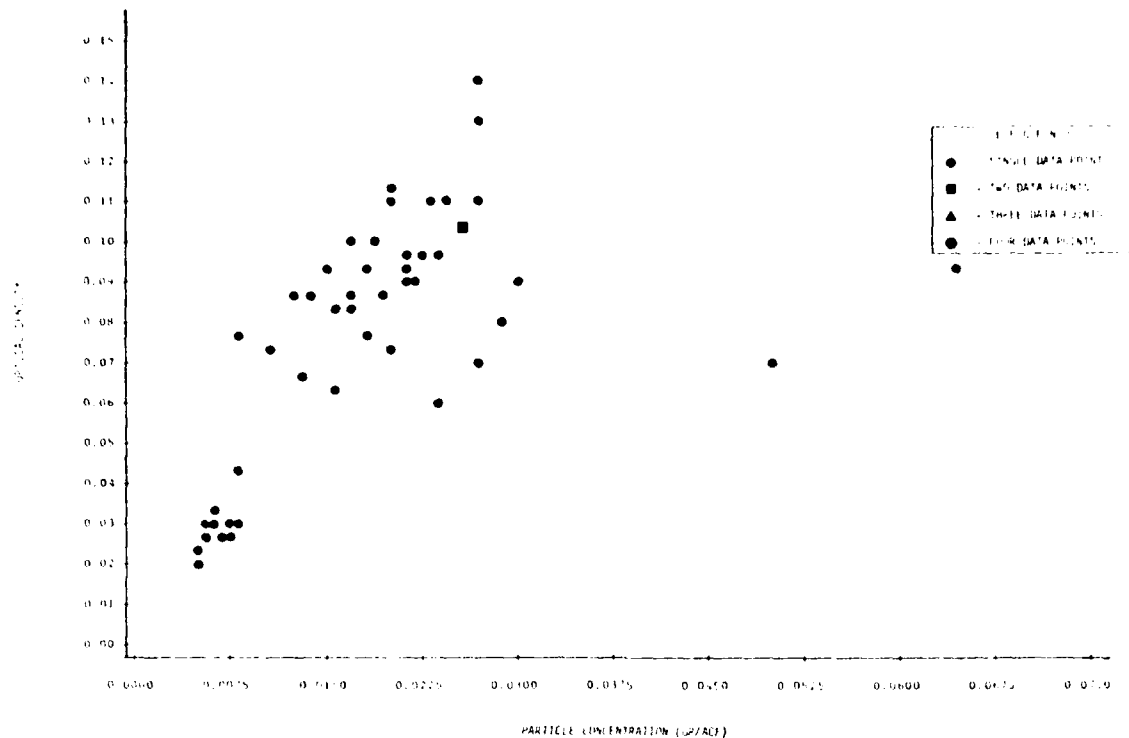


Figure 3. Scatter Plot - Particle Concentration (GR/ACF) vs. Optical Density: Represents All Data Collected, Regardless of Test Method

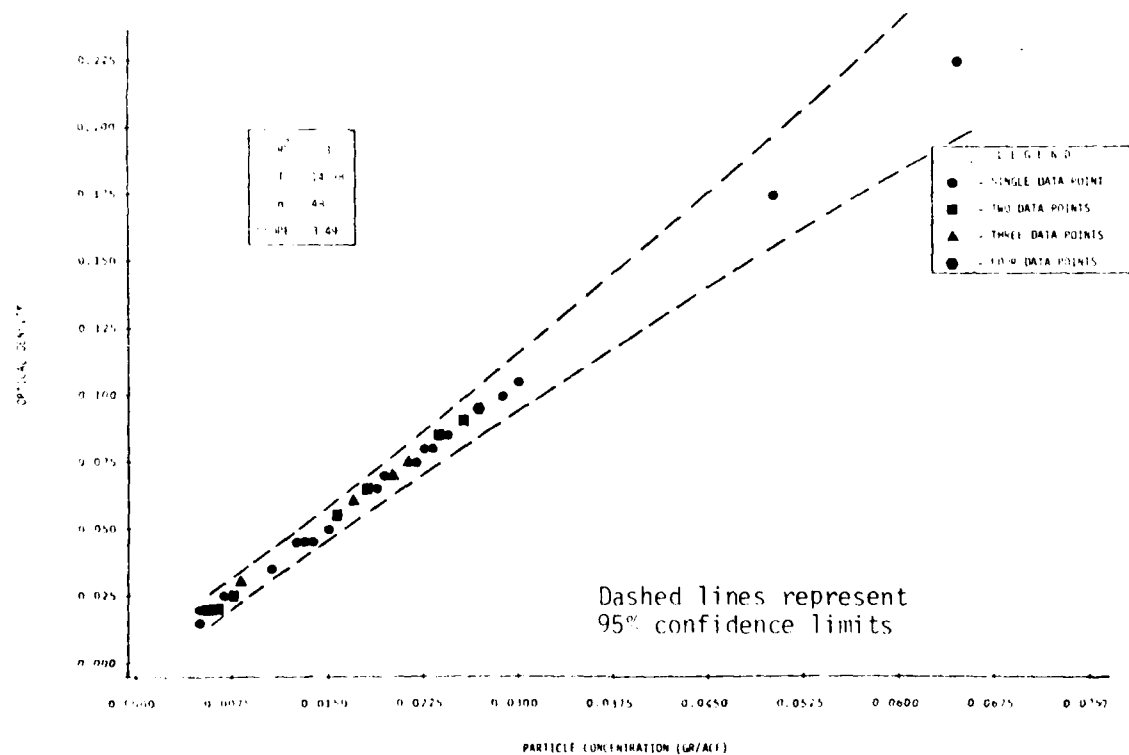


Figure 4. Linear Model - Particle Concentration (GR/ACF) vs. Optical Density: Represents the Best Fit of Data in Figure 3 by a Least Squares Linear Regression Analysis

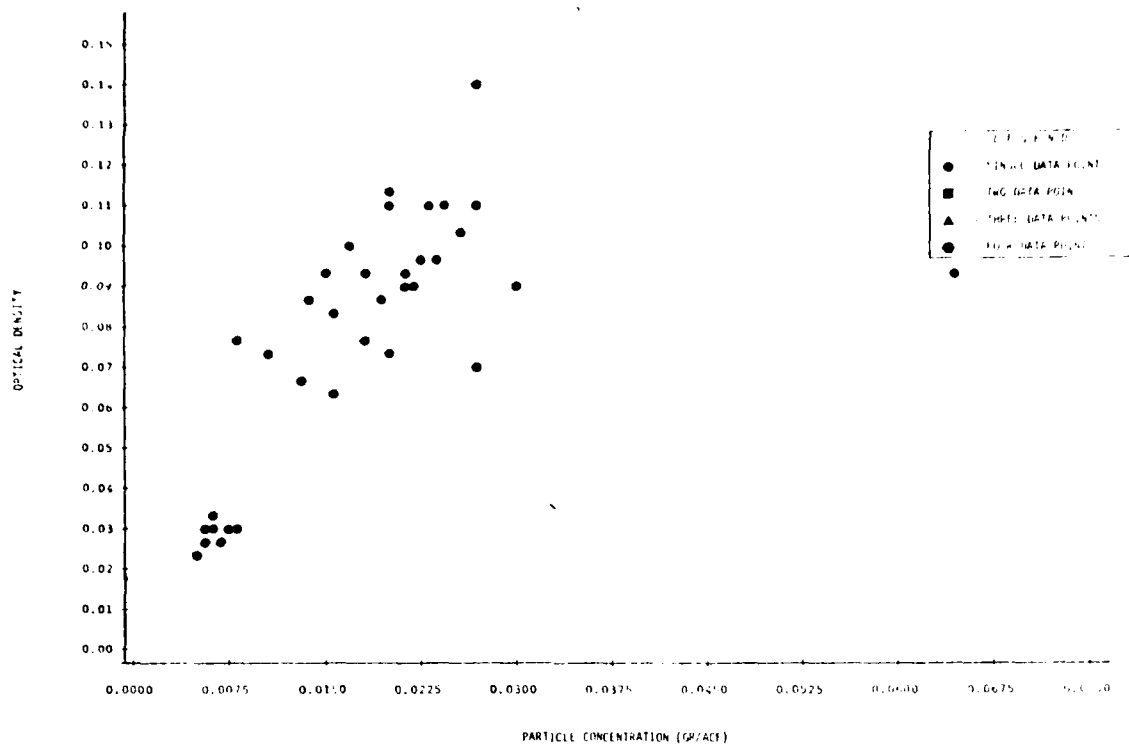


Figure 5. Scatter Plot - Particle Concentration (GR/ACF) vs. Optical Density: Represents All Data at Both Forge Shops Where Mass Concentration Was Determined by the In-Stack Filter Test Method

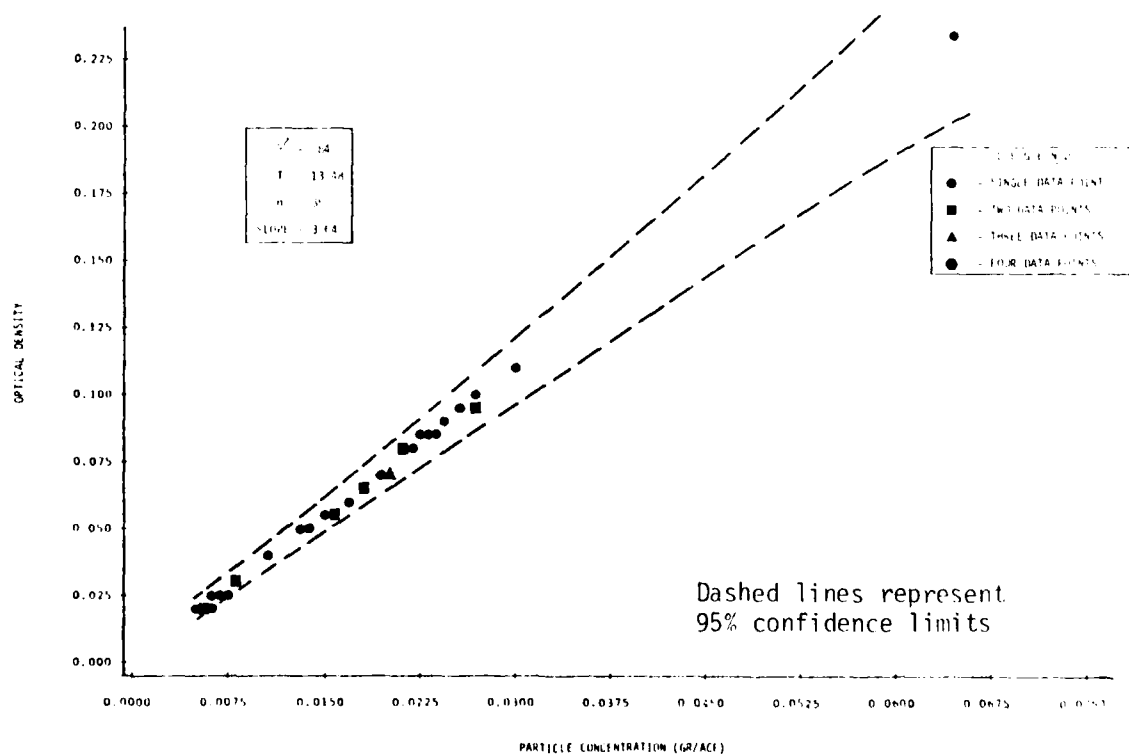


Figure 6. Linear Model - Particle Concentration (GR/ACF) vs. Optical Density: Represents the Best Fit of Data in Figure 5 by a Least Squares Linear Regression Analysis

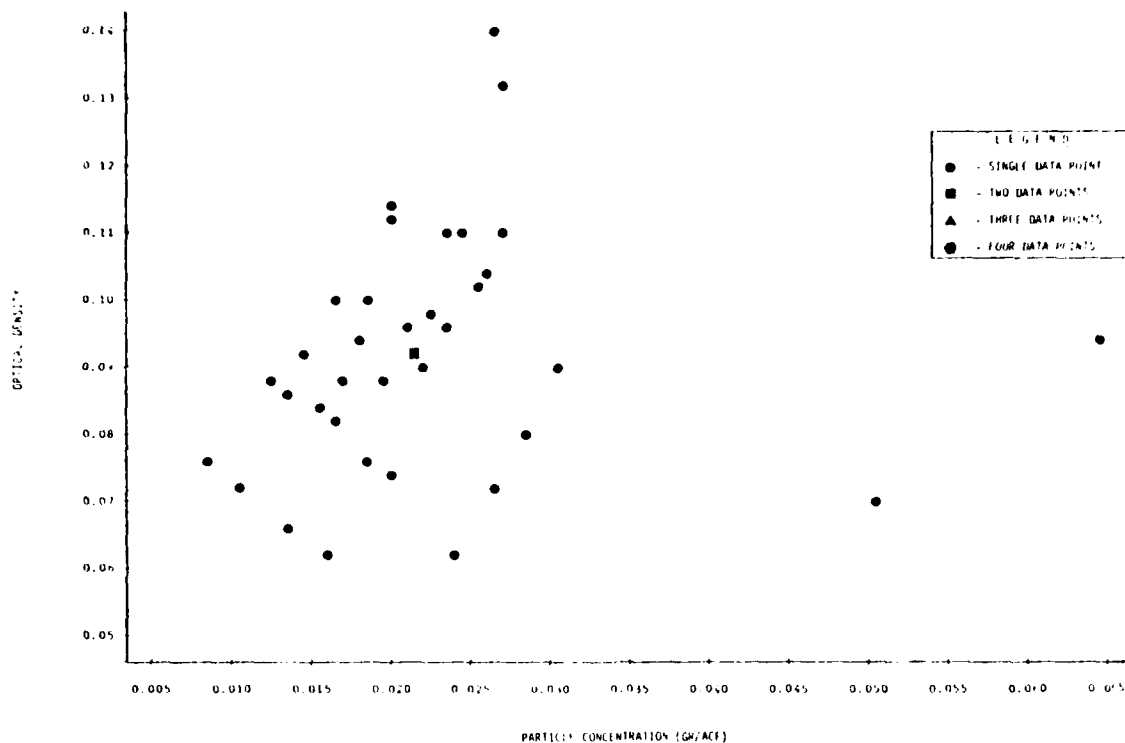


Figure 7 Scatter Plot - Particle Concentration (GR/ACF) vs. Optical Density: Represents All Data Collected at the Erie Press Line, Regardless of Test Method

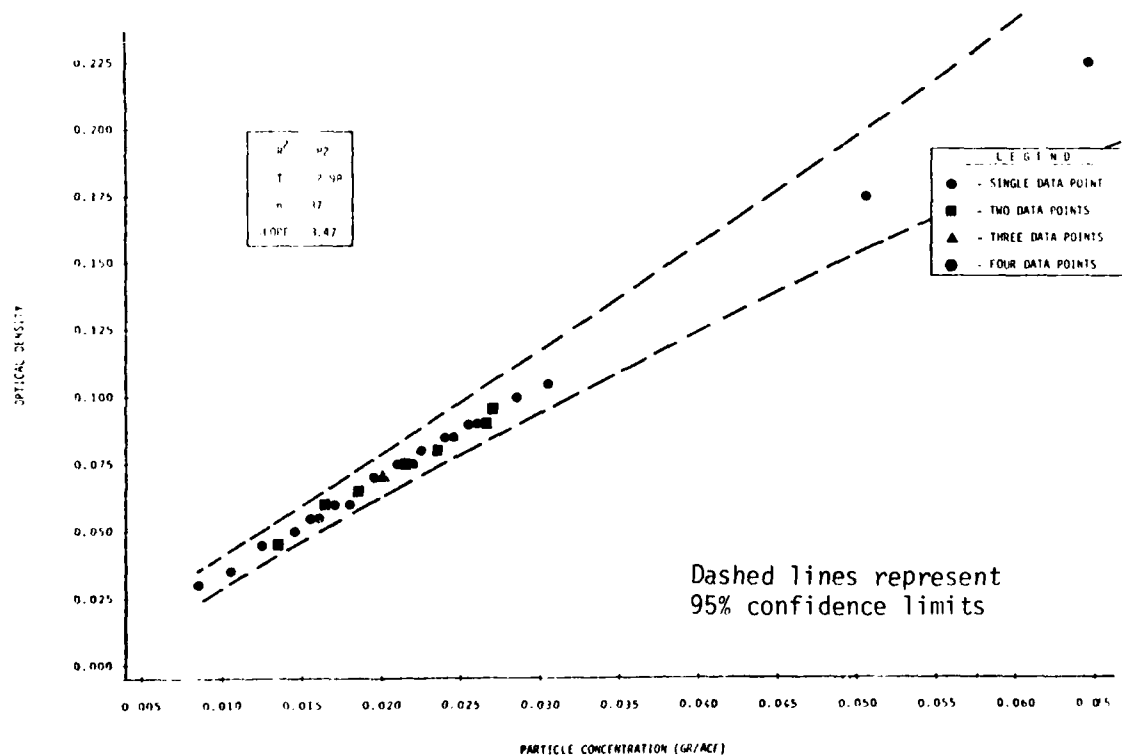


Figure 8. Linear Model - Particle Concentration (GR/ACF) vs. Optical Density: Represents the Best Fit of Data in Figure 7 by a Least Squares Linear Regression Analysis

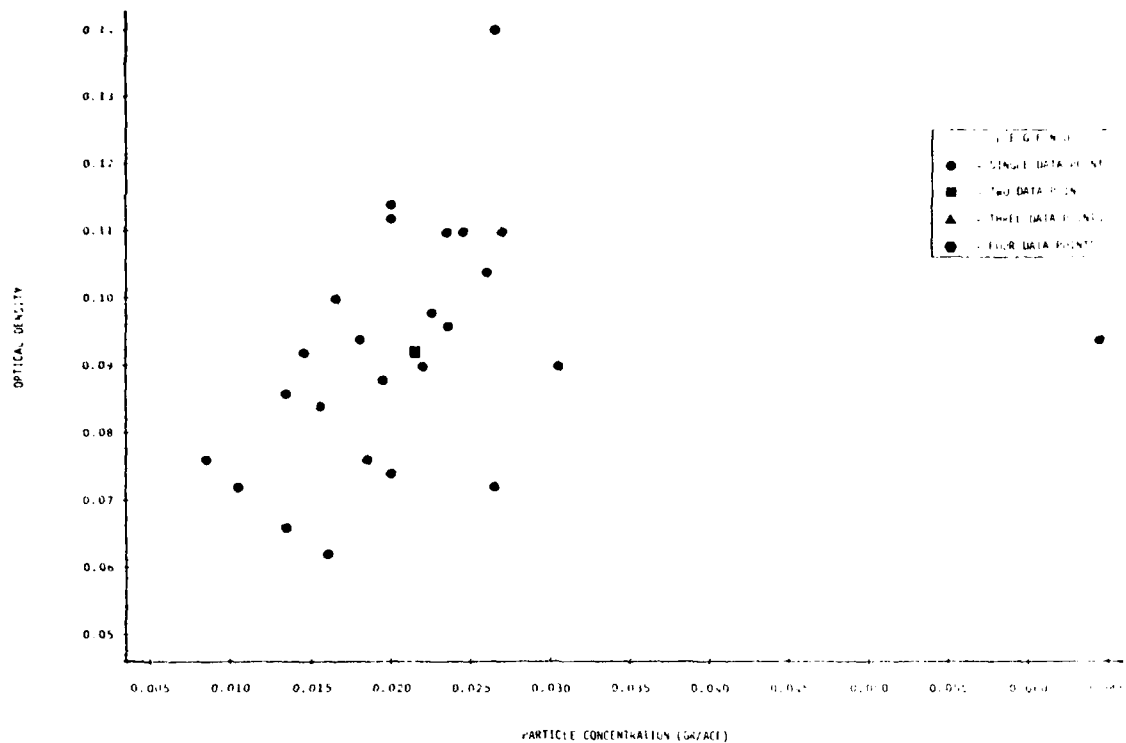


Figure 9. Scatter Plot - Particle Concentration (GR/ACF) vs. Optical Density: Represents Data Collected at the Erie Press Line Where Mass Concentration Was Determined by the In-Stack Filter Test Method

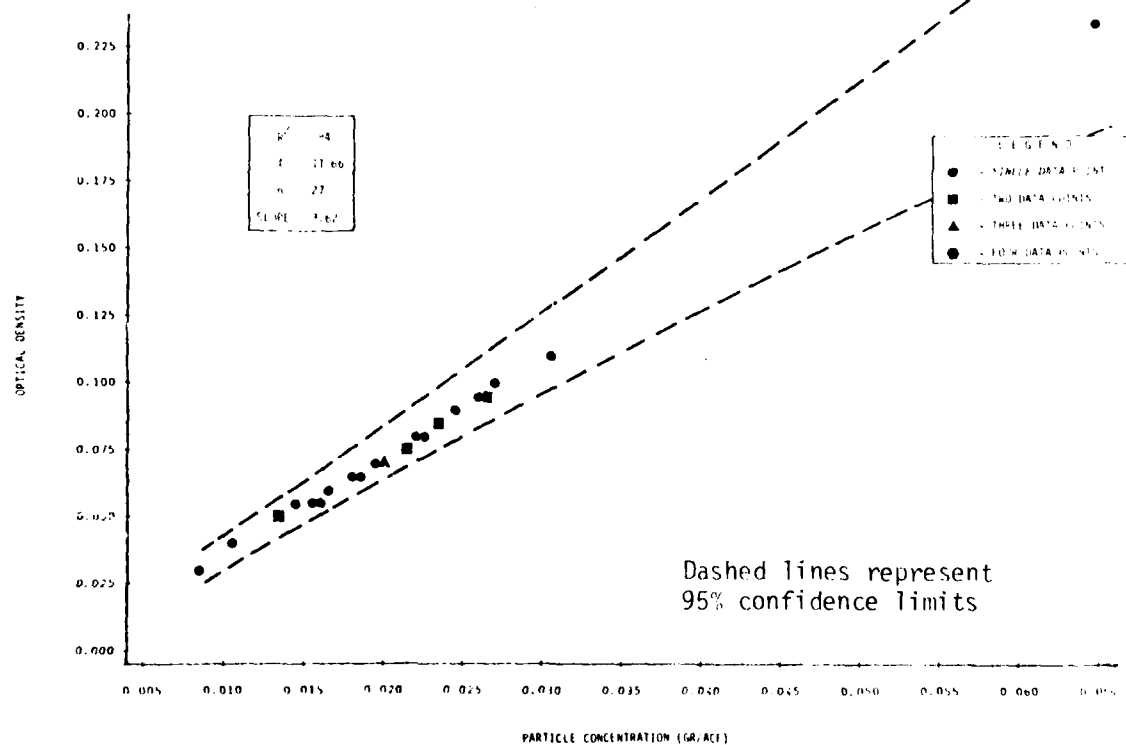


Figure 10. Linear Model - Particle Concentration (GR/ACF) vs. Optical Density: Represents the Best Fit of Data in Figure 9 by a Least Squares Linear Regression Analysis

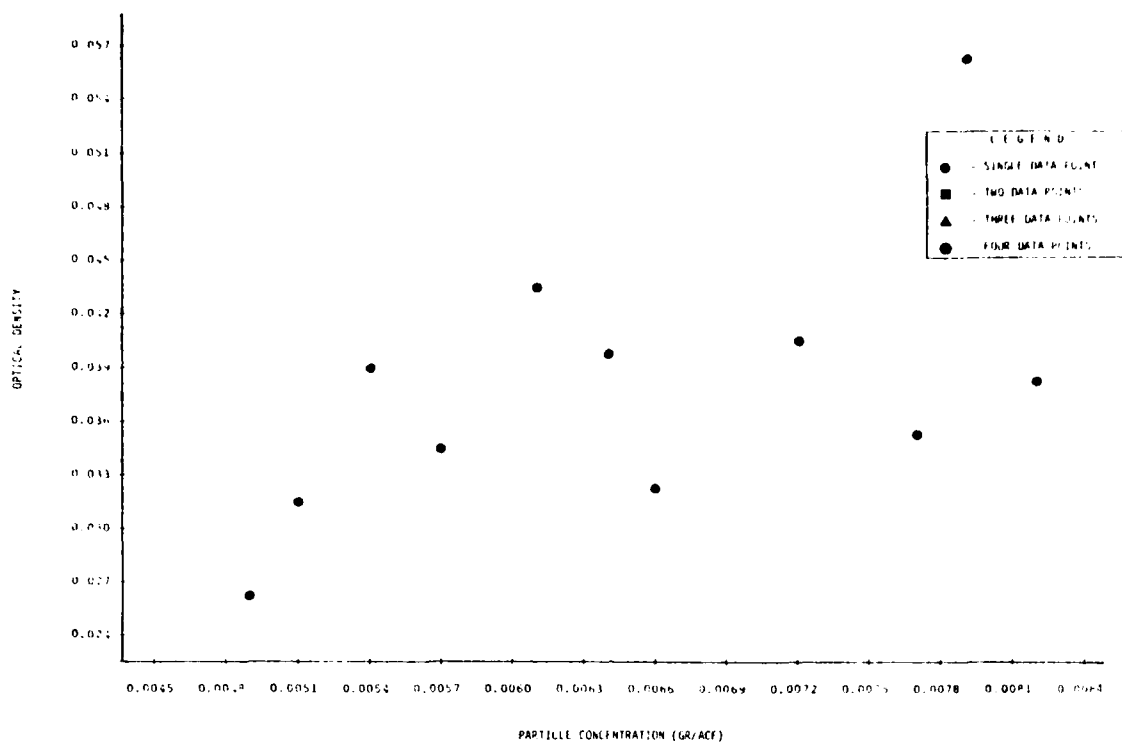


Figure 11: Scatter Plot - Particle Concentration (GR/ACF) vs. Optical Density: Represents Data Collected at Flinchbaugh, Regardless of Test Method and Before the Opacity Data Was Corrected

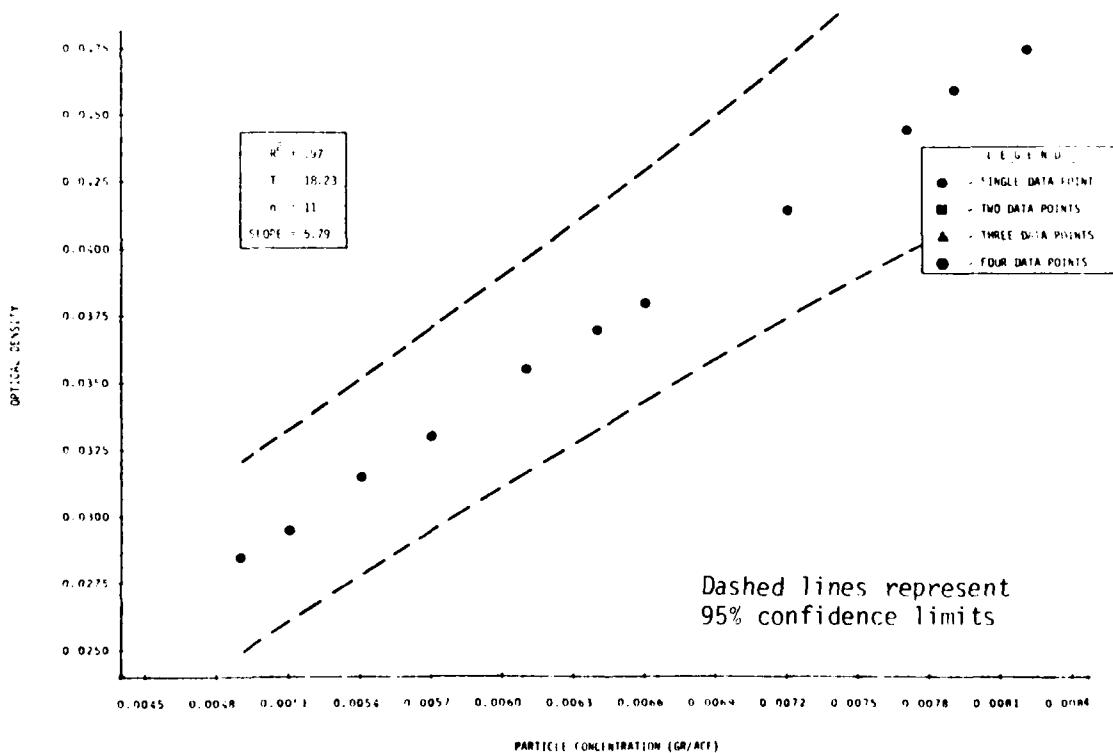


Figure 12: Linear Model - Particle Concentration (GR/ACF) vs. Optical Density: Represents the Best Fit of Data in Figure 11 by a Least Squares Linear Regression Analysis

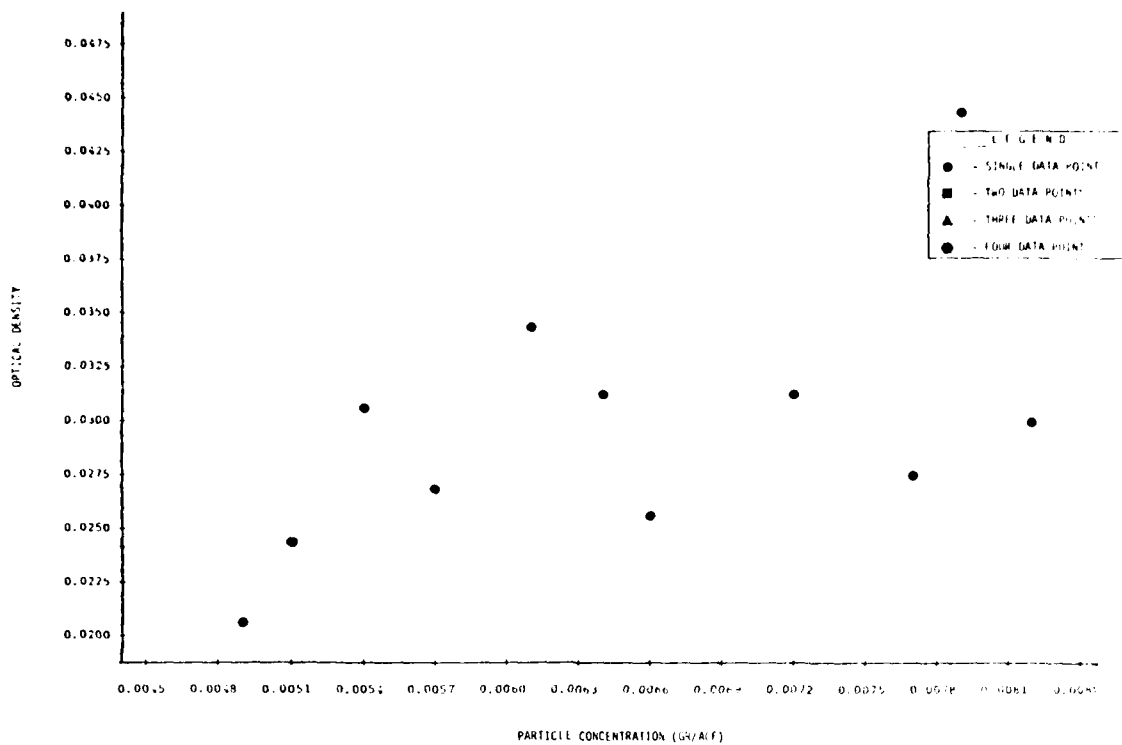


Figure 13. Scatter Plot - Particle Concentration (GR/ACF) vs. Optical Density: Represents Data Collected at Flinchbaugh, Regardless of Test Method and After the Opacity Data Was Corrected

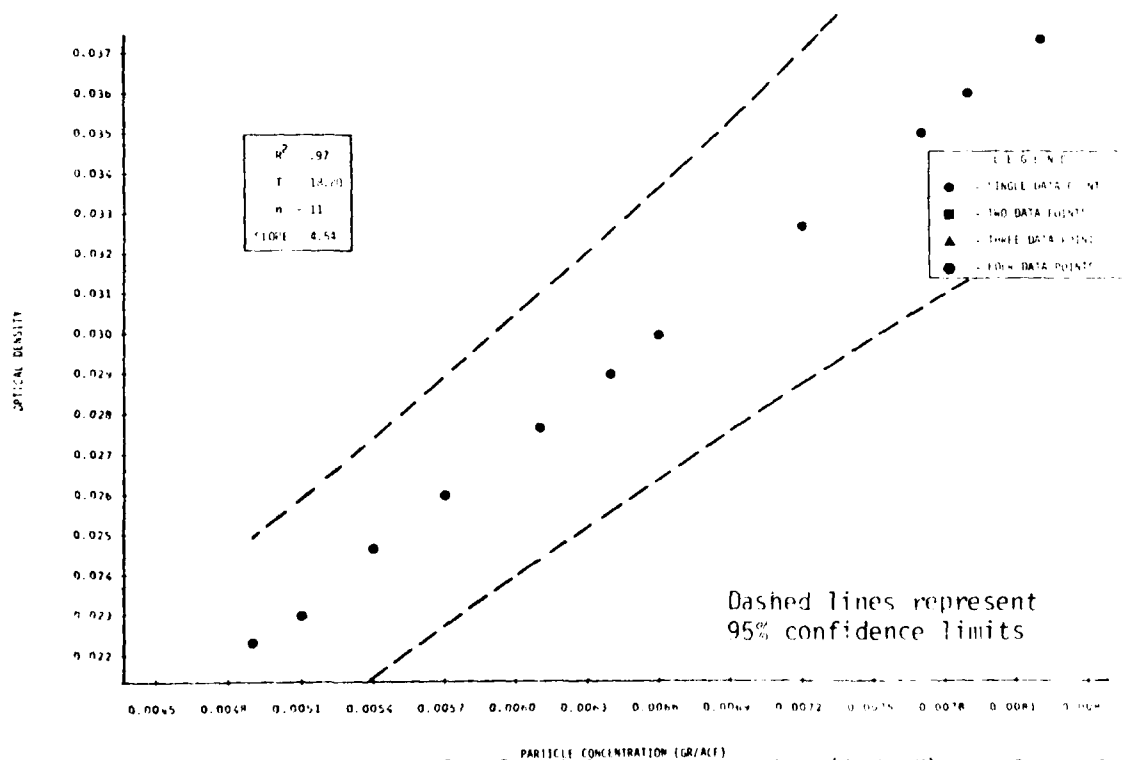


Figure 14. Linear Model - Particle Concentration (GR/ACF) vs. Optical Density: Represents the Best Fit of Data in Figure 13 by a Least Squares Linear Regression Analysis

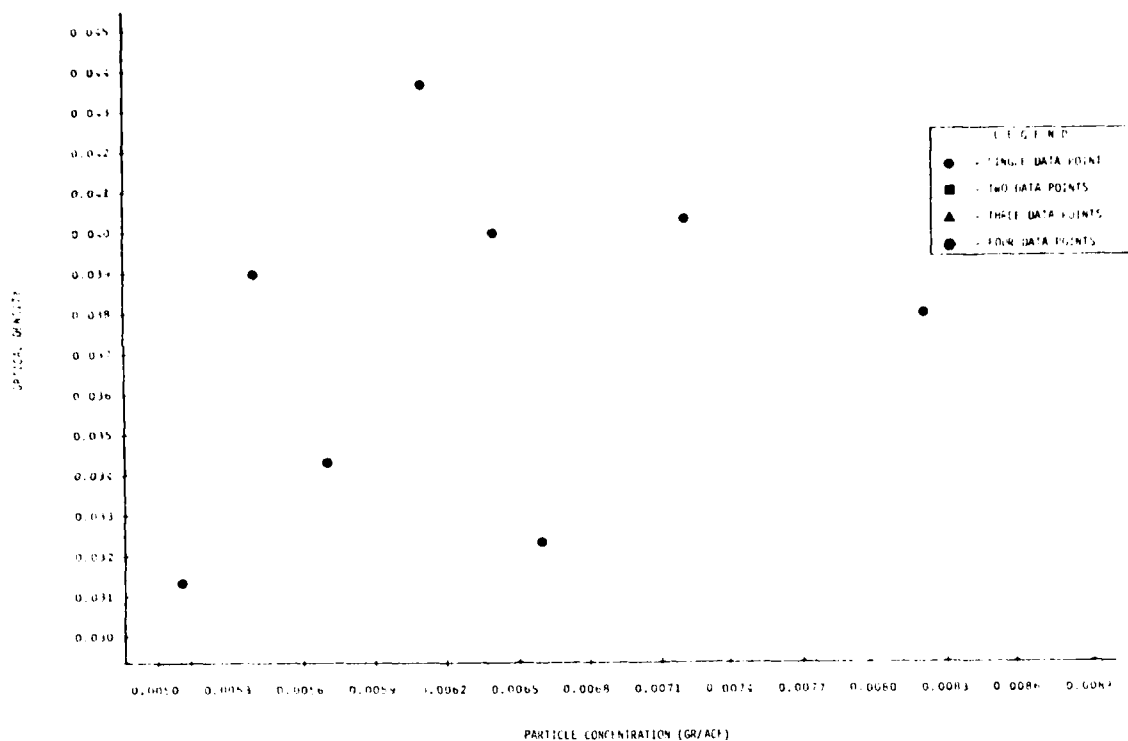


Figure 15. Scatter Plot - Particle Concentration (GR/ACF) vs. Optical Density: Represents Data Collected at Flinchbaugh Where Mass Concentration Was Determined by the In-Stack Filter Test Method and Before the Opacity Data Was Corrected

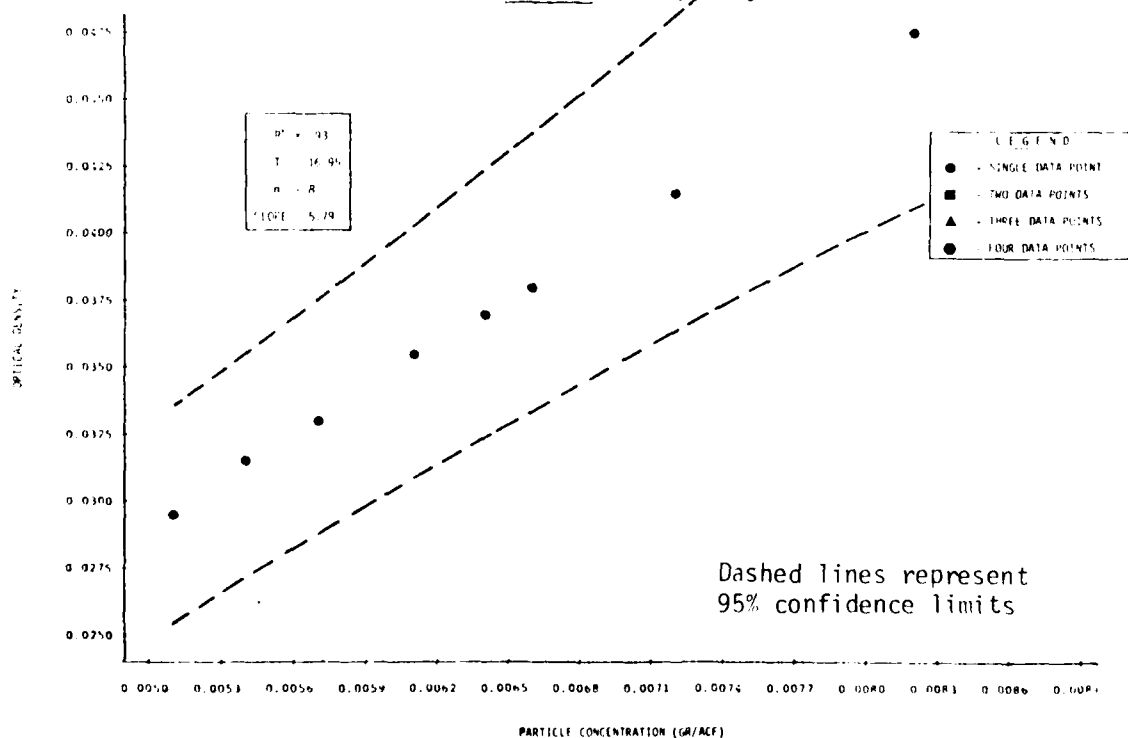


Figure 16. Linear Model - Particle Concentration (GR/ACF) vs. Optical Density: Represents the Best Fit of Data in Figure 15 by a Least Squares Linear Regression Analysis

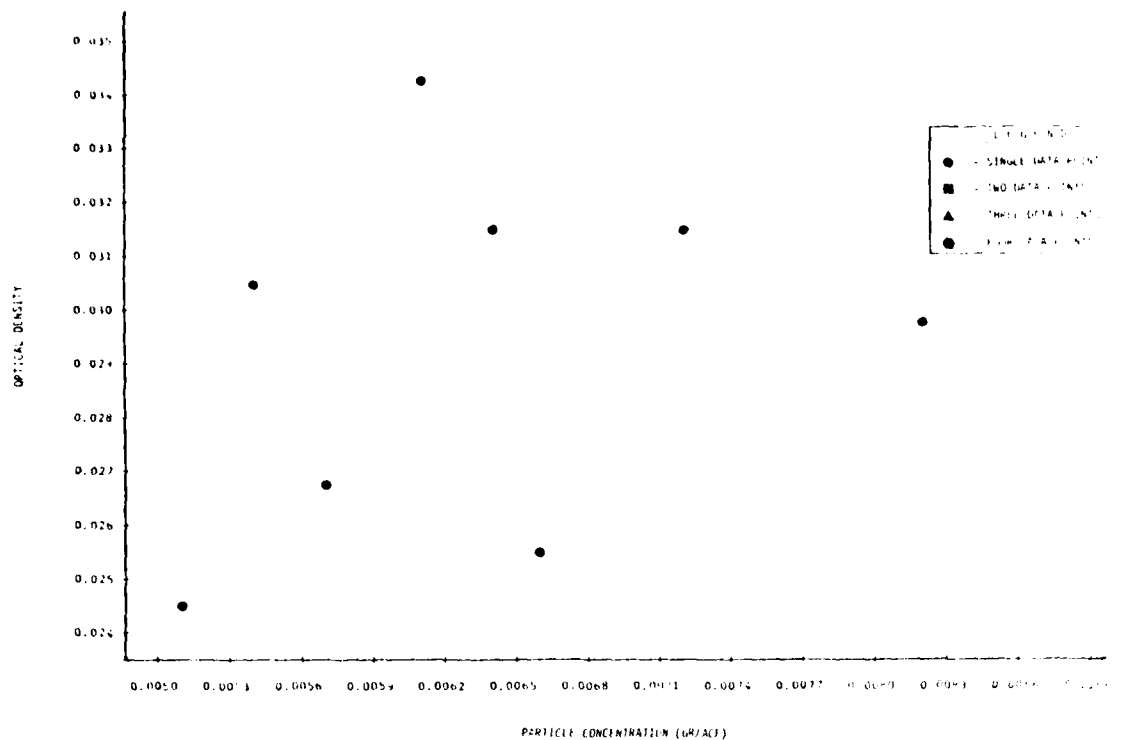


Figure 17. Scatter Plot - Particle Concentration (GR/ACF) vs. Optical Density: Represents Data Collected at Flinchbaugh Where Mass Concentration Was Determined by the In-Stack Filter Test Method and After the Opacity Data Was Corrected

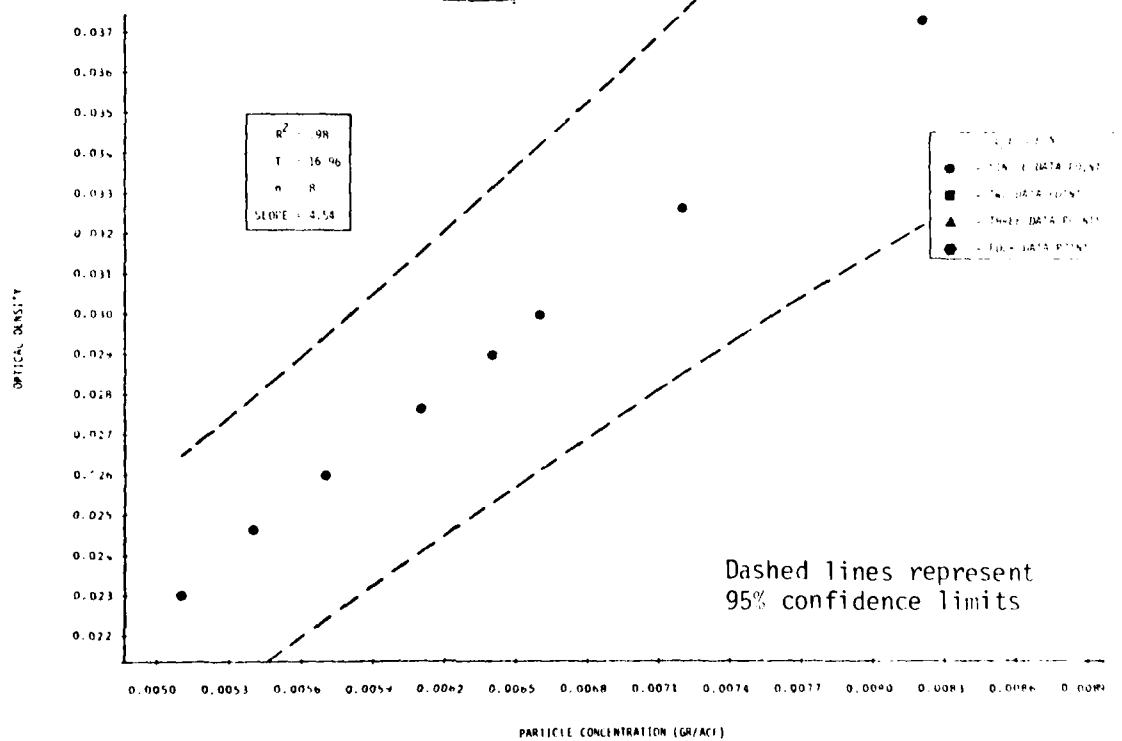


Figure 18. Linear Model - Particle Concentration (GR/ACF) vs. Optical Density: Represents the Best Fit of Data in Figure 17 by a Least Squares Linear Regression Analysis

Before proceeding with this discussion, it is important to clarify several aspects of the sixteen figures. The optical density scales for the top and bottom graphs on each page are not identical. The bottom graph has an expanded optical density scale over the scale of the top graph. This expanded optical density scale results because the predicted optical density values cover a wider range than the observed values (based on the measured particle concentrations). Another item of importance is observed when the graphs of the Flinchbaugh data are compared to the graphs of the total data base and the data from the Erie press line. It would appear from the scatter plots that the Flinchbaugh data does not exhibit a good correlation between particle concentration and optical density (Figures 11, 13, 15, and 17). However, these scatter plots are deceiving because the optical density and particle concentration scales cover such a narrow range, as compared to Figure 3 for example. The Flinchbaugh data are confined to relatively low values of optical density and particle concentration, when compared to the data generated at the Erie press line. Actually, the Flinchbaugh data shows less variability than the Erie press line data, and the data points for Flinchbaugh are closely grouped.

For all eight data sets which were analyzed, the results indicate that there is a strong correlation between particle concentration and optical density. This correlation is supported by the statistical parameters contained in Table 5. All data sets yield calculated t statistics which are greater than 10 (range of 11.66 to 16.96); this is at a 95 percent confidence level (0.05 level of significance) and for $n - 1$ degrees of freedom. The corresponding t statistics from statistical tables are 2.3 or less (range of 2.013 to 2.306). These statistics verify that the slopes of the regression

Table 5

STATISTICAL PARAMETERS FOR THE EIGHT DATA SETS ANALYZED

Data Set	n	Slope	t Statistic* (Calculated)	t Statistic* (From Tables)	r ² (Coefficient of Determination)	r (Coefficient of Correlation)
All data	48	3.49	14.98	2.013	0.83	0.91
All IS data	35	3.64	13.48	2.031	0.84	0.92
All data at Erie	37	3.47	12.98	2.027	0.82	0.91
IS data at Erie	27	3.62	11.66	2.052	0.84	0.92
All data at Flinchbaugh (uncorrected)	11	5.79	18.23	2.201	0.97	0.98
All data at Flinchbaugh (corrected)	11	4.54	18.20	2.201	0.97	0.98
IS data at Flinchbaugh (uncorrected)	8	5.79	16.95	2.306	0.93	0.96
IS data at Flinchbaugh (corrected)	8	4.54	16.96	2.306	0.98	0.99

*These values are for $n - 1$ degrees of freedom and a level of significance of 0.05 (95% confidence level).

lines which describe the relationship between particle concentration and optical density are significantly different than zero in all cases.

A measure of the degree of association between particle concentration and optical density is the coefficient of determination or r^2 . Basically, the coefficient of determination is a measure of the uncertainty in predicting the dependent variable, optical density. The closer r^2 is to 1, the greater is said to be the association between optical density and particle concentration. As seen from Table 5, the r^2 values are all greater than 0.8 (range of 0.82 to 0.98). This illustrates a high degree of association between the two variables. An interpretation of r^2 values is that they indicate the proportional reduction in the variability of the dependent variable attained by the use of information about the independent variable. For example, a coefficient of determination of 0.83, indicates that 83 percent of the variation of optical density can be explained by the variation of particle concentration. The other 17 percent of the variation between the two variables must be explained by other factors such as particle size distribution, composition, shape, etc. It is obvious, then, that there is a high degree of correlation between particle concentration and optical density.

The relationship between particle concentration and optical density is defined by the slope of the regression line as illustrated by equation 8. Table 5 lists the slopes of the regression lines for the eight data sets which were analyzed. The regression lines are graphically represented in Figures 4, 6, 8, 10, 12, 14, 16, and 18. As seen from these figures and Table 5, it appears that the slopes of the regression lines for the various data sets are different in most cases. Student t tests were performed with

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various pairs of data sets to determine if the slopes of the regression lines were significantly different at the 95 percent confidence level. The results of the t tests indicated that the differences between the slopes for the uncorrected Flinchbaugh data (slope = 5.79) and the corrected Flinchbaugh data (slope = 4.54) were statistically significant. It was expected that the uncorrected and corrected Flinchbaugh data would exhibit different slopes for their regression lines, since that was the purpose of reducing the Flinchbaugh data to a basis equivalent to that of the Erie press line data. The adjustment to the opacity data for Flinchbaugh served to reduce the slope of the regression line, and make the data fall more in line with the data from the Erie press line.

Additional t tests showed that there was no statistical significance (at the 95% confidence level) to the perceived differences between the slopes of the regression lines for the following pairs of data sets:

- All data (slope = 3.49) versus all data where the in-stack filter was used (slope = 3.64); calculated t statistic equals -0.944.
- All data for Erie press (slope = 3.47) versus data for the Erie press where the in-stack filter was used (slope = 3.62); calculated t statistic equals -0.8221.
- All corrected Flinchbaugh data (slope = 4.54) versus corrected Flinchbaugh data where the in-stack filter was used (slope = 4.54); calculated t statistic equals zero.
- All data for Erie press (slope = 3.47) versus all corrected Flinchbaugh data (slope = 4.54); calculated t statistic equals -0.666.

- All data for Erie press (slope = 3.47) versus all uncorrected Flinchbaugh data (slope = 5.79); calculated t statistic equals -1.434.

At the 95 percent confidence level and for a two tailed test, the corresponding t statistics from statistical tables for the pairs of data sets listed above are ± 2.00 or greater. Obviously, the calculated t statistics are within the range of ± 2.00 , which indicates that the differences between the slopes are not statistically significant. The observed differences between the slopes for the pairs of data sets listed above can be attributed to sampling errors or sampling variations.

The last item in the above listing indicates that there is not a statistically significant difference between the slopes of the regression lines for all data at the Erie press line and all uncorrected Flinchbaugh data. However, the t statistic is -1.434, which approaches the critical value of -2.00. When a student t test is performed with the in-stack filter data at the Erie press (slope = 3.62) and the uncorrected in-stack filter data at the Flinchbaugh forge shop (slope = 5.79), the calculated t statistic is -3.331. There are 33 degrees of freedom for this paired data set. For a two tailed test at the 95 percent confidence level, the critical t statistic from statistical tables is -2.036. The difference between the slopes of the regression lines for these two data sets is statistically significant at the 95 percent confidence level. Based on this difference between the slopes, it can be concluded that the emission characteristics and the relationship between particle concentration and optical density are different for each of the two forge shops. This conclusion is expected, because it was known that

the stack diameters and process operating conditions were different for the two forge shops. Once the opacity data from the Flinchbaugh forge shop was reduced to a basis equivalent to the Erie press, the difference between the slopes of the regression lines for any data sets for the two forge shops is not statistically significant at the 95 percent confidence level. This indicates that it is not possible to use the relationship between optical density and particle concentration developed at one forge shop for predictive purposes at a second forge shop unless the appropriate adjustments are made to the data to account for the differences between the two shops.

It is difficult to assess the effect that the various particulate test methods had on the study results, because the majority of the tests were conducted using the in-stack filter test method. Thirty-five out of forty-eight tests were conducted with the in-stack filter. When all data, regardless of test method, was considered, there was not a significant difference between the slopes of the regression lines for the two forge shops. However, when only the in-stack filter test data was considered, there was a statistically significant difference between the slopes. This appears to suggest that the particulate test method does have an effect on the study results. None of the other data seems to suggest that the particulate test method is critical. Intuitively, one would think that the particulate test methods which were used in this study should produce similar results, if the tests were conducted properly. It is also obvious that the sampling rates were similar among the test methods, but the size of the instrument inserted into the stack was different for each of the three test methods. The Gehman impactor had the largest cross-sectional area, the in-stack filter the next largest and the Method 5 probe the smallest. It is likely that the exhaust

gas flow characteristics around the sampling instrument may be different for each of these sampling methods; hence there could be differences in the test results.

Prediction of Particle Concentration from Opacity Data

Based on JACA's tests results, there is a strong correlation between particle concentration and optical density for the uncontrolled exhausts at the Erie press line of the SAAP and the Flinchbaugh forge shop. This relationship for the Erie press line is described by the equation:

$$D = 3.49C \quad (10)$$

where D = optical density (expressed as a fraction, $0 \leq D \leq 1$)

C = particle concentration (gr/acf)

For predictive purposes, JACA has chosen to use the regression line established by the least squares linear regression analysis of the total data base, because there is a greater degree of confidence associated with the greater number of data points (48). Also, it was determined that there was not a statistically significant difference between the slopes of the regression lines for the other subsets of the total data base once the corrections were made to the Flinchbaugh opacity data. Although there may be a concern with the method of determining particle concentration, it is thought that the data representing a combination of test methods is more realistic because it represents an average situation. Thus, equation 10 best describes the relationship between particle concentration and optical density at the 95 percent confidence level.

To estimate particle concentration from opacity data, it is necessary to obtain time averaged opacity or optical density values, typically over a one- to two-hour period. Opacity should be measured with a properly installed and calibrated transmissometer to ensure that the measurements are accurate and consistent. Because of the cyclic nature of the forge shop emissions, it is important to monitor opacity over a sufficiently long period of time to smooth out these short-term emission fluctuations. However, it is not apparent from JACA's study how monitoring periods of greater than one or two hours will affect the opacity/mass emission relationship. Once a reliable measure of optical density is obtained, equation 10 can be used to predict particle concentration values.

It should be realized that particle concentrations predicted from equation 10 should not be considered as absolute values. As previously mentioned, there can be considerable variation of particle concentration values. Figure 4 graphically illustrates the relationship established by equation 10. The 95 percent confidence limits establish the bounds of the particle concentration/optical density relationship. In essence, one can be 95 percent sure that the concentration/optical density values will fall within the confidence limits established in Figure 4. However, this is not to say that small sample sizes or individual measurements will not be outside of the confidence limits.

Figure 4 also shows that there is greater confidence associated with optical density values of less than about 0.10 and corresponding particle concentrations of less than about 0.03 gr/acf. The confidence limits expand beyond these values. The relationship between optical density and particle concentration is more reliable for lower opacities and mass emissions.

At this point, it is reasonable to use equation 10 to predict particle concentrations from opacity data for the exhaust at the Erie press line of the SAAP. Strictly speaking, it is apparent that this relationship will not hold for other forge shop exhausts. Use of the relationship established by equation 10 at other forge shops requires an analysis of the emission characteristics of the exhaust similar to this study. The study results at another forge shop can then be compared to the results of JACA's study to determine if the optical density/particle concentration relationship is consistent between forge shops. For example, the appropriate relationship between particle concentration and optical density for the Flinchbaugh Forge shop is $D = 5.79 C$. The Flinchbaugh test results could be used for predictive purposes at the Erie press line only after the appropriate corrections were made to the Flinchbaugh opacity data.

However, for predictive estimates of particle concentrations, the empirical relationship of equation 10 could be used at other forge shops provided the forging operations are similar in most respects to the Erie press line (e.g. production rates, oil usage, type of oil, etc.) and the diameter of the exhaust ductwork is known. Opacity observations could be made at the outlet of the exhaust using EPA Method 9 procedures. The average opacity values over one-hour periods or more could then be corrected to account for the difference in stack diameter between a given forge shop exhaust and the Erie press exhaust. Once the corrected average opacity is converted to optical density, an estimate of particle concentration may be obtained.

PARTICLE SIZE DISTRIBUTION

Twelve particle sizing tests were conducted during this study, the results of which are summarized in Tables 6 through 16. Two particle sizing tests were performed at the SAAP with a Brinks impactor, while nine particle sizing tests were conducted at the SAAP using a Gelman Sciences, Inc. cascade impactor. One particle sizing test was done at the Flinchbaugh forge shop using the Gelman cascade impactor.

The results of the particle sizing tests were of limited use because of the nature of the test method or problems with the analysis of the material collected in the impactors. As seen in Table 6, the Brinks impactor tests resulted in a large quantity of material collected in the sampling train (nozzle, tube, and glassware) prior to the impactor. This weight was two to three times the particulate weight in the impactor. The collection of material prior to the impactor, obviously, would alter the particle size distribution before the material was collected in the impactor. For this reason, the Brinks impactor test results were considered not to be representative of the actual particle size distribution. The Gelman cascade impactor is inserted directly into the stack, while the Brinks impactor is housed in the sample box, outside of the stack. For this reason, the Gelman impactor generates more reliable particle sizing results, because the only component of the sampling train prior to the impactor is the nozzle. However, there are still considerable quantities of material collected in the nozzle, and the size distribution determined by the Gelman impactor is likely to have been altered. Thus, the measured size distributions should not be taken as absolute distributions, but can be used for comparative purposes.

Table 6

SCRANTON APP - ERIE PRESS LINE
BRINKS IMPACTOR PARTICLE SIZING DATA

	<u>Test 1</u>			<u>Test 2</u>		
	Wt. Grams	Cum. Wt. in Impactor	Cum. Wt. %	Wt. Grams	Cum. Wt. in Impactor	Cum. Wt. %
Nozzle	.0029			.0033		
Tube	.0089			.0092		
Glassware	.0034	.0103	100.0	.0051	.0100	100.0
Total (Before Imp.)	.0152			.0176		
Stage 1 (2.6 m)	.0007	.0069	67.0	.00105	.0049	49.0
Stage 2 (1.5 m)	.0005	.0062	60.2	.00065	.00385	38.5
Stage 3 (1.0 m)	.0004	.0057	55.3	.0008	.0032	32.0
Stage 4 (0.54 m)	.0007	.0053	51.4	.0015	.0024	24.0
Stage 5 (0.33 m)	.0006	.0046	44.7	.0004	.0009	9.0
Back-Up (Glass Wool)	.0040	.0040	38.8	.0005	.0005	5.0
Wt. Collected in Impactor	.0069			.0049		
Total Wt. Collected	.0221			.0225		

Particle Grain Loading from Impactor Data

$$V_{inst1} = \frac{17.71 \times 8.096 \times 29.744}{539.5}$$

$$= 7.905 \text{ dscf}$$

$$C_s = \frac{.0221 \text{ gm}}{7.905} \times 15.432455$$

$$= 0.0431 \text{ gr/dscf}$$

$$V_{mstd} = \frac{17.71 \times 12.076 \times 29.538}{554.82}$$

$$= 11.39 \text{ dscf}$$

$$C_s = \frac{.0225}{11.39} \times 15.432455$$

$$= 0.0305 \text{ gr/dscf}$$

Table 7

FLINCHBAUGH PRODUCTS, INC.

CASCADE IMPACTOR PARTICLE SIZING DATA*

IMPACTOR TEST "A"

Impactor Stage	Particle Size Range On Impact Stage @ 86.83° F (μm)	Stage D50 @ 70° F (μm)	Stage D50 @ 86.83° F (μm)	Weight Collected Per Stage (gm)	Weight Percent Per Stage (%)	Cumulative Weight the D50 Size (gm)	Cumulative Weight % the D50 Size (%)
Pre-Impactor	9.700 -	9.600	9.700	0.0007	5.4	0.0123	94.6
1	6.211 - 9.700	6.150	6.211	0.0003	2.3	0.0120	92.3
2	3.890 - 6.211	3.850	3.890	0.0004	3.1	0.0116	89.2
3	2.505 - 3.890	2.480	2.505	0.0004	3.1	0.0112	86.2
4	1.505 - 2.505	1.490	1.505	0.0012	9.2	0.0100	76.9
5	0.980 - 1.505	0.970	0.980	0.0025	19.2	0.0075	57.7
6	0.621 - 0.980	0.615	0.621	0.0024	18.5	0.0051	39.2
7	0.358 - 0.621	0.355	0.358	0.0015	11.5	0.0036	27.7
Backup Filter	- 0.353	-	-	0.0036	27.7	-	-
Total	-	-	-	0.0130	100.0	-	-

*Sampling Rate - 0.648 acfm.

Table 2

SCRANTON AAP, ERIE PRESS LINE

CASCADE IMPACTOR PARTICLE SIZING DATA*

IMPACTOR TEST "B"

Impactor Stage	Particle Size Range On Impactor Stage @ 100° F (μm)	Stage D ₅₀ @ 70° F (μm)	Stage D ₅₀ @ 100° F (μm)	Weight Collected Per Stage (gm)	Weight Percent Per Stage (%)	Cumulative Weight ≤ the D ₅₀ Size (gm)	Cumulative Weight % ≤ the D ₅₀ Size (%)
Pre-Impactor	8.976 -	8.800	8.976	-			
1	5.712 - 8.975	5.600	5.712	0.0010			
2	3.570 - 5.712	3.500	3.570	0.0012			
3	2.244 - 3.570	2.200	2.244	0.0032			
4	1.377 - 2.244	1.350	1.377	0.0025			
5	0.898 - 1.377	0.880	0.898	0.0045			
6	0.561 - 0.898	0.550	0.561	0.0041			
7	0.321 - 0.561	0.315	0.321	0.0041			
Backup Filter	- 0.321	-	-	0.0077			
Total	-	-	-	-			

*Sampling Rate - 0.774 acfm.

Table 9

SCRANTON AAP, ERIE PRESS LINE

CASCADE IMPACTOR PARTICLE SIZING DATA*

IMPACTOR TEST "C"

Particle Size		Stage D50 @ 70° F (μm)	Stage D50 @ 94° F (μm)	Weight Collected Per Stage (gm)	Weight Percent Per Stage (%)	Cumulative Weight < the D50 Size (gm.)	Cumulative Weight % < the D50 Size (%)
Impactor Stage	Impactor Stage @ 94° F (μm)						
Pre- Impactor	8.976 -	8.800	8.976	0.0032	12.15	0.0223	87.5
1	5.712 - 8.976	5.600	5.712	0.0008	3.1	0.0215	84.3
2	3.570 - 5.712	3.500	3.570	0.0003	1.2	0.0212	83.1
3	2.244 - 3.570	2.200	2.244	0.0012	4.7	0.0200	78.4
4	1.377 - 2.244	1.350	1.377	0.0005	2.0	0.0195	76.5
5	0.893 - 1.377	0.860	0.898	0.0097	38.0	0.0098	38.4
6	0.561 - 0.898	0.550	0.561	0.0012	4.7	0.0086	33.7
7	0.321 - 0.561	0.315	0.321	0.0005	2.0	0.0081	31.8
Backup Filter	- 0.321	-	-	0.0081	31.2	-	-
Total	-	-	-	0.0255	100.0	-	-

*Sampling Rate - 0.772 acfm.

Table 10

SORANTEL AND, ERIE PRESS LINE

CASCADE IMPACTOR PARTICLE SIZING DATA*

IMPACTOR TEST "D"

Impactor Stage	Particle Size Range On Impactor Stage @ 90° F (μm)	Stage D ₅₀ @ 70° F (μm)	Stage D ₅₀ @ 90° F (μm)	Weight Collected Per Stage (gm)	Weight Percent Per Stage (%)	Cumulative Weight the D ₅₀ Size (gm)	Cumulative Weight % the D ₅₀ Size (%)
Pre-Impactor	8.67 -	8.50	8.670	0.0465	77.5	0.0135	22.4
1	5.61 - 8.67	5.50	5.610	0.0005	0.8	0.0130	21.5
2	3.468 - 5.61	3.40	3.468	0.0002	0.3	0.0128	21.3
3	2.244 - 3.468	2.20	2.244	0.0014	2.3	0.0114	19.0
4	1.326 - 2.244	1.30	1.326	0.0016	2.7	0.0098	16.3
5	0.857 - 1.326	0.84	0.857	0.0020	3.3	0.0078	13.0
6	0.551 - 0.857	0.54	0.551	0.0027	4.5	0.0051	8.5
7	0.3162 - 0.551	0.31	0.316	0.0014	2.3	0.0037	6.2
Backup Filter	-	-	-	0.0037	6.2	-	-
Total	-	-	-	0.0600	100.0	-	-

*Sampling Rate - 0.806 acfm.

Table 11

SCRANTON AAP, ERIE PRESS LINE

CASCADE IMPACTOR PARTICLE SIZING DATA*

IMPACTOR TEST "E"

Impactor Stage	Particle Size Range On Impactor Stage @ 91.1° F (μm)	Stage D ₅₀ @ 70° F (μm)	Stage D ₅₀ @ 91.1° F (μm)	Weight		Weight Percent Per Stage (%)	Cumulative	
				Collected Per Stage (gm)	the D ₅₀ Size (gm)		Weight the D ₅₀ Size (gm)	Cumulative Weight % the D ₅₀ Size (%)
Pre-Impactor	8.976 -	8.80	8.976	0.0105	0.0145	42.0	0.0145	58.0
1	5.712 - 8.976	5.60	5.712	0.0001	0.0144	0.4	0.0144	57.6
2	3.570 - 5.712	3.50	3.570	0.0005	0.0139	2.0	0.0139	55.6
3	2.295 - 3.570	2.25	2.295	0.0017	0.0122	6.3	0.0122	48.8
4	1.377 - 2.295	1.35	1.377	0.0014	0.0108	5.6	0.0108	43.2
5	0.877 - 1.377	0.86	0.877	0.0033	0.0075	13.2	0.0075	30.0
6	0.561 - 0.877	0.55	0.561	0.0019	0.0056	7.6	0.0056	22.4
7	0.326 - 0.561	0.32	0.326	0.0012	0.0044	4.8	0.0044	17.6
Backup Filter	-	-	-	0.0044	-	17.6	-	-
Total	-	-	-	0.0250	-	100.0	-	-

*Sampling Rate - 3.7800 acfm.

Table 12

SCRANTON AAP, ERIF PRESS LINE

CASCADE IMPACTOR PARTICLE SIZING DATA*

IMPACTOR TEST "F"

Impactor Stage	Particle Size Range On Impactor Stage @ 86.3° F (µm)	Stage D50 @ 70° F (µm)	Stage D50 @ 86.3° F (µm)	Weight Collected Per Stage (gm)	Weight Percent Per Stage (%)	Cumulative	
						Weight < the D50 Size (gm)	Weight < the D50 Size (%)
Pre-Impactor	8.989-	8.90	8.989	0.0221	48.0	0.0239	51.9
1	7.777 - 8.989	7.70	7.777	0.0003	0.6	0.0236	51.3
2	3.586 - 7.777	3.55	3.586	0.0003	0.6	0.0233	50.7
3	2.525 - 3.586	2.50	2.525	0.0034	7.4	0.0199	43.3
4	1.364 - 2.525	1.35	1.364	0.0020	4.3	0.0175	39.0
5	0.889 - 1.364	0.88	0.889	0.0033	7.2	0.0146	31.8
6	0.556 - 0.889	0.55	0.556	0.0033	7.2	0.0113	24.6
7	0.323 - 0.556	0.32	0.323	0.0028	6.1	0.0085	18.5
Backup Filter	-	-	-	0.0085	18.5	-	-
Total	-	-	-	0.0460	100.0	-	-

*Sampling Rate - 0.766 acfm.

Table 13

SCRANTON AAP, ERIE PRESS LINE

CASCADE IMPACTOR PARTICLE SIZING DATA*

IMPACTOR TEST "G"

Particle Size		Stage D ₅₀	Stage D ₅₀	Weight	Weight	Cumulative	Cumulative
Range On		@ 70° F	@ 93.8° F	Collected	Percent	weight	Weight
Impactor	Impactor Stage	(μ m)	(μ m)	Per Stage	Per Stage	the D ₅₀	the D ₅₀
Stage	@ 93.8° F (μ m)			(gm)	(%)	Size (gm)	Size (%)
Pre-Impactor	8.670 -	8.50	8.670	0.0144	70.2	0.0061	29.7
1	5.610 - 8.670	5.50	5.610	0.0	0.0	0.0061	29.7
2	3.468 - 5.610	3.40	3.468	0.0002	1.0	0.0059	28.7
3	2.193 - 3.468	2.20	2.244	0.0008	3.9	0.0051	24.8
4	1.326 - 2.193	1.30	1.326	0.0003	1.5	0.0048	23.3
5	0.857 - 1.326	0.84	0.857	0.0006	2.9	0.0042	20.4
6	0.551 - 0.857	0.54	0.551	0.0013	6.3	0.0029	14.1
7	0.316 - 0.551	0.31	0.3162	0.0015	7.3	0.0014	6.8
Backup Filter	-	-	-	0.0014	6.8	-	-
Total	-	-	-	0.0205	100.0	-	-

*Sampling Rate - 0.797 acfm.

Table 14

SCRANTON AAP, ERIE PRESS LINE

CASCADE IMPACTOR PARTICLE SIZING DATA*

IMPACTOR TEST "H"

Impactor Stage	Particle Size		Stage D ₅₀ @ 70° F (μm)	Stage D ₅₀ @ 96.25° F (μm)	Weight Collected Per Stage (gm)		Cumulative Weight the D ₅₀ Size (gm)		Cumulative Weight % the D ₅₀ Size (%)	
	Range On	Impact Stage @ 96.25° F (μm)			Per Stage	Weight Per Stage (%)				
Pre-Impactor	8.670 -		8.50	9.670	?					
1	5.610 - 8.670		5.50	5.610	0.0					
2	3.468 - 5.610		3.40	3.468	0.0005					
3	2.193 - 3.468		2.15	2.193	0.0013					
4	1.326 - 2.193		1.30	1.326	0.0012					
5	0.857 - 1.326		0.84	0.857	0.0029					
6	0.551 - 0.857		0.54	0.551	0.0026					
7	0.316 - 0.551		0.31	0.316	0.0012					
Backup Filter	-		-	-	0.0067					
Total	-		-	-	-					

*Sampling Rate - 0.819 acfm.

Table 15

SCRANTON AAP, ERIE PRESS LINE

CASCADE IMPACTOR PARTICLE SIZING DATA*

IMPACTOR TEST "I"

Impactor Stage	Particle Size Range On Impact Stage @ 78.5° F (μm)	Stage D ₅₀ @ 70° F (μm)	Stage D ₅₀ @ 78.5° F (μm)	Weight Collected Per Stage (gm)	Weight Percent Per Stage (%)	Cumulative	
						Weight the D ₅₀ Size (gm)	Weight % the D ₅₀ Size (%)
Pre-Impactor	8.744 -	8.70	8.744	?			
1	5.528 - 8.744	5.50	5.528	0.0002			
2	3.467 - 5.528	3.45	3.467	0.0004			
3	2.211 - 3.467	2.20	2.211	0.0008			
4	1.327 - 2.211	1.32	1.327	0.0010			
5	0.864 - 1.327	0.86	0.864	0.0023			
6	0.543 - 0.864	0.54	0.543	0.0018			
7	0.312 - 0.543	0.31	0.312	0.0020			
Backup Filter	-	-	-	0.0035			
Total	-	-	-	-			

*Sampling Rate - 0.801 acfm.

Table 16

SCRANTON AAP, ERIE PRESS LINE

CASCADE IMPACTOR PARTICLE SIZING DATA*

IMPACTOR TEST "J"

Impactor Stage	Particle Size		Stage D ₅₀ @ 70° F (μm)	Stage D ₅₀ @ 70.8° F (μm)	Weight Collected Per Stage (gm)	Weight Percent Per Stage (%)	Cumulative weight ≤ the D ₅₀ Size (gm)	Cumulative Weight % ≤ the D ₅₀ Size (%)
	Range On	Impactor Stage @ 70.8° F (μm)						
Pre-Impactor	9.10 -		9.10	9.10	?			
1	5.90 - 9.10		5.90	5.90	0.0005			
2	3.70 - 5.90		3.70	3.70	0.0007			
3	2.35 - 3.70		2.35	2.35	0.0016			
4	1.42 - 2.35		1.42	1.42	0.0019			
5	0.92 - 1.42		0.92	0.92	0.0038			
6	0.58 - 0.92		0.58	0.58	0.0029			
7	0.34 - 0.58		0.34	0.34	0.0018			
Backup Filter	-		-	-	0.0023			
Total	-		-	-	-			

*Sampling Rate - 0.727 acfm.

Four of the ten particle sizing tests using the Gelman impactor were considered totally invalid, because the nozzle and preimpactor washes were combined when the particulate weights were analyzed. When the nozzle was removed from the impactor, material from the nozzle dropped into the pre-impactor and the washes were subsequently combined. While these tests were not valid for the purpose of particle sizing, they could be used for determining total particulate concentration. Impactor test "F" was considered invalid for the purpose of determining total concentration because the nozzle wash was contaminated. However, this did not affect the particle sizing results.

Figure 19 graphically represents the particle size distributions generated by the six tests that were considered most reliable. This figure illustrates that there are three totally different particle size distributions. Paired tests A and C, F and E, and D and G appear to have generated similar size distributions, but the distributions between the paired tests are obviously dissimilar. It is interesting to note the similarity between the distributions for Test A and Test C. Test A was conducted at the Flinchbaugh forge shop, while Test C was conducted at the Erie press line of the SAAP. At times, there appear to be similarities between the particle characteristics at the two forge shops.

It was previously stated that more than 80 percent of the variation in optical density may be attributed to the variation in particle concentration and that the remaining variation must be attributed to other factors. Figure 19 supports the premise that variations in particle size distributions do account for a portion of the remaining variation between particle concentration and optical density. The particle size distribution does vary temporally as was expected.

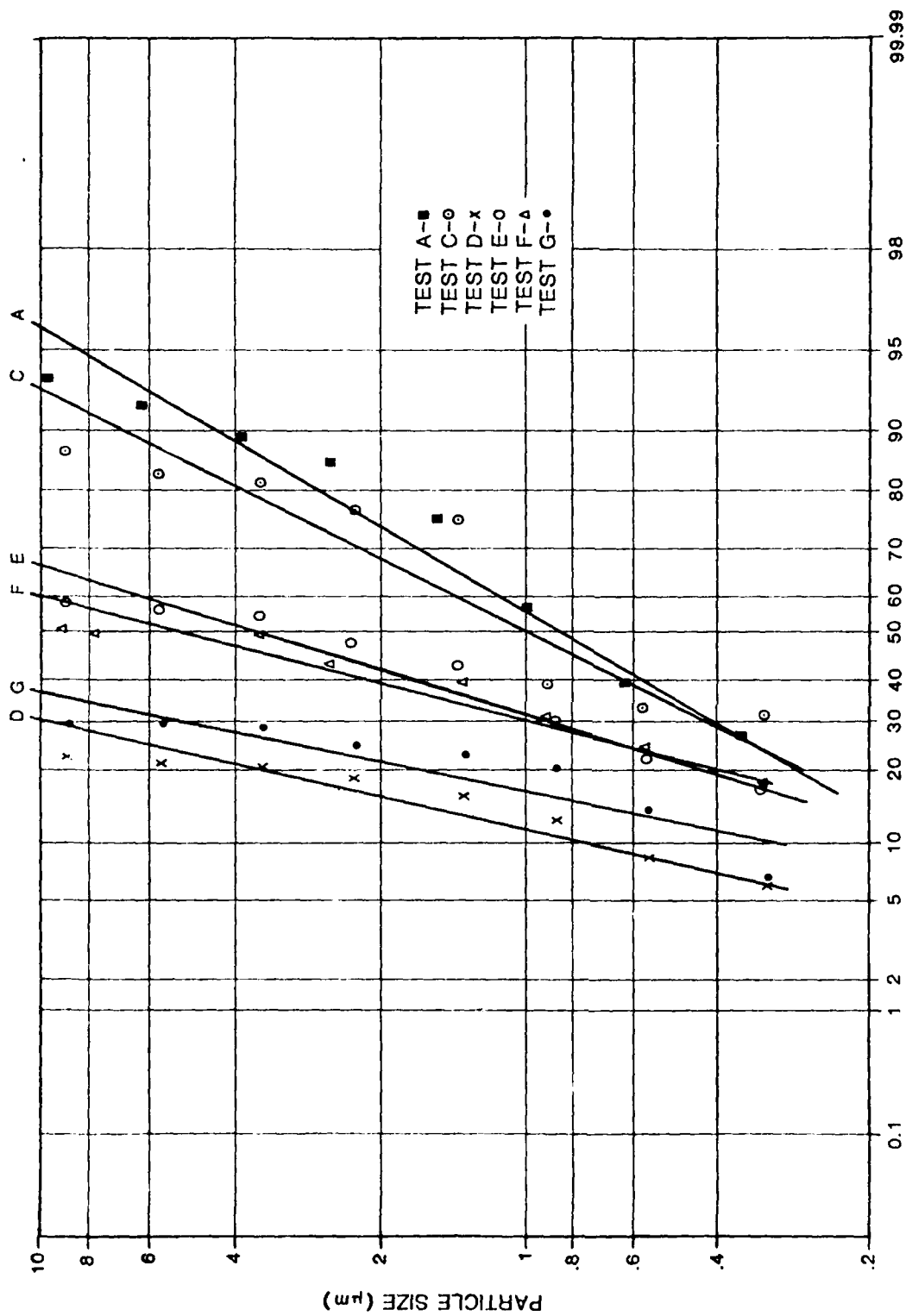


Figure 19. Particle Size Distribution for Six Impactor Tests; Cumulative Weight Percent Less Than Stated Size.

RECOMMENDATION

Although this study was concerned primarily with the Erie press line at Scranton Army Ammunition Plant, the information generated supports the use of an empirical relationship for other forge shop exhausts. However, the average opacity values over periods of 1 hour or more should be corrected to account for the difference in stack diameter between a given forge shop exhaust and the Erie press line exhaust. Once the corrected average opacity is converted to optical density, an estimate of particulate concentration may be obtained.

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